RED ELÉCTRICA DE ESPAÑA

RED ELÉCTRICA internacional

Integration of large-scale wind in the grid – The Spanish Experience

Portland, OREGON, 24th-25th July 2008

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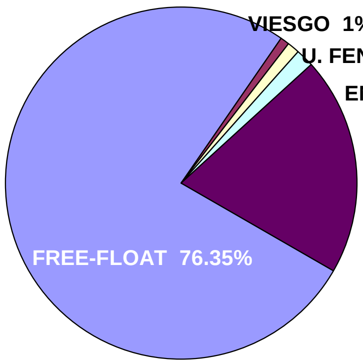
RED ELÉCTRICA, pioneer company (1985) in business management of Transmission and System Operation as unbundled activities:

- Operates the system and guarantees the continuity of supply
- Designs, builds and maintains the transmission network

Shareholder structure
at 31-12-07



** SEPI (Spanish State owned holding Company)*

	Transmission Network	2007
400 kV km	Red Eléctrica	17.142
	Others	38
	Total	17.180
< 220 kV km	Red Eléctrica	16.548
	Others	261
	Total	16.809
Transf.	Red Eléctrica	58.359
Capacity	Others	800
400/AT (MVA)	Total	59.159

Red Eléctrica Internacional Sub-group

- Red Eléctrica Internacional (REI) has the mission of managing and development the international strategy of REE Group

- REI, subsidiary 100% of REE, is the head of REI Subgroup and holder of the totality of international investments of the Group REE in LatAm (TDE - Bolivia and REDESUR - Peru)

- Two main areas of business have been defined in the international activity:
  - Investment & Operation
  - Consultancy Services (System operation, electric sector regulatory advice, Control Systems, Engineering, Generation and transmission planning etc.)

INTRODUCTION

In early 90's…

Energy dependence	~63% of primary energy in 1986; ~85% in 2007 Contribution of 1/3 on the Trading Deficit (9.4% of GDP); only Oil 1/4
Wind potential	High wind location, national renewable resource, energy dependence reduction New sector, job creation, sales potential
Technology	[MW/unit]: 1985- 0.1 MW; 1990- 0.5 MW; 1995-0.8 MW … 2007 >4 MW Different technology than thermal generators: initially lower performances (f, V) Power electronics bring solutions to control f, V, Q, disconnections…
Power System	Random contribution to demand coverage Location: new grid developments Sudden disconnections → System stability → SECURITY OF SUPPLY
Conditions	Technical: little knowledge on wind, but little impact in system security. Regulatory: safe scheme to promote wind energy Administrations Agents/Promoters

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Wind power integration

- Problematic issues for a TSO
- REE solutions

Maximum wind penetration studies

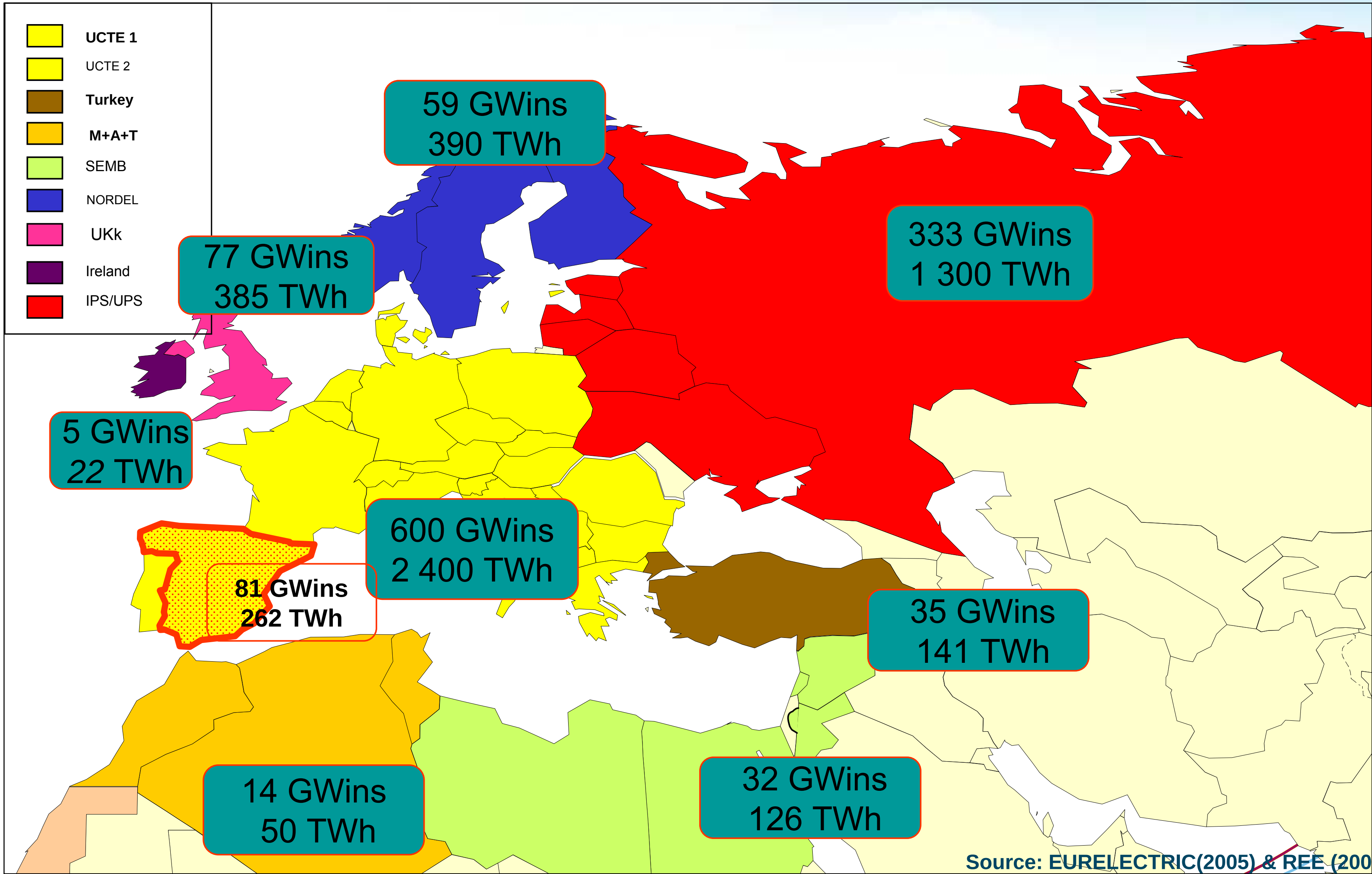
Control centre for renewable energies (CECRE)

Calculation of wind farm limitations (GEMAS)

Economic framework

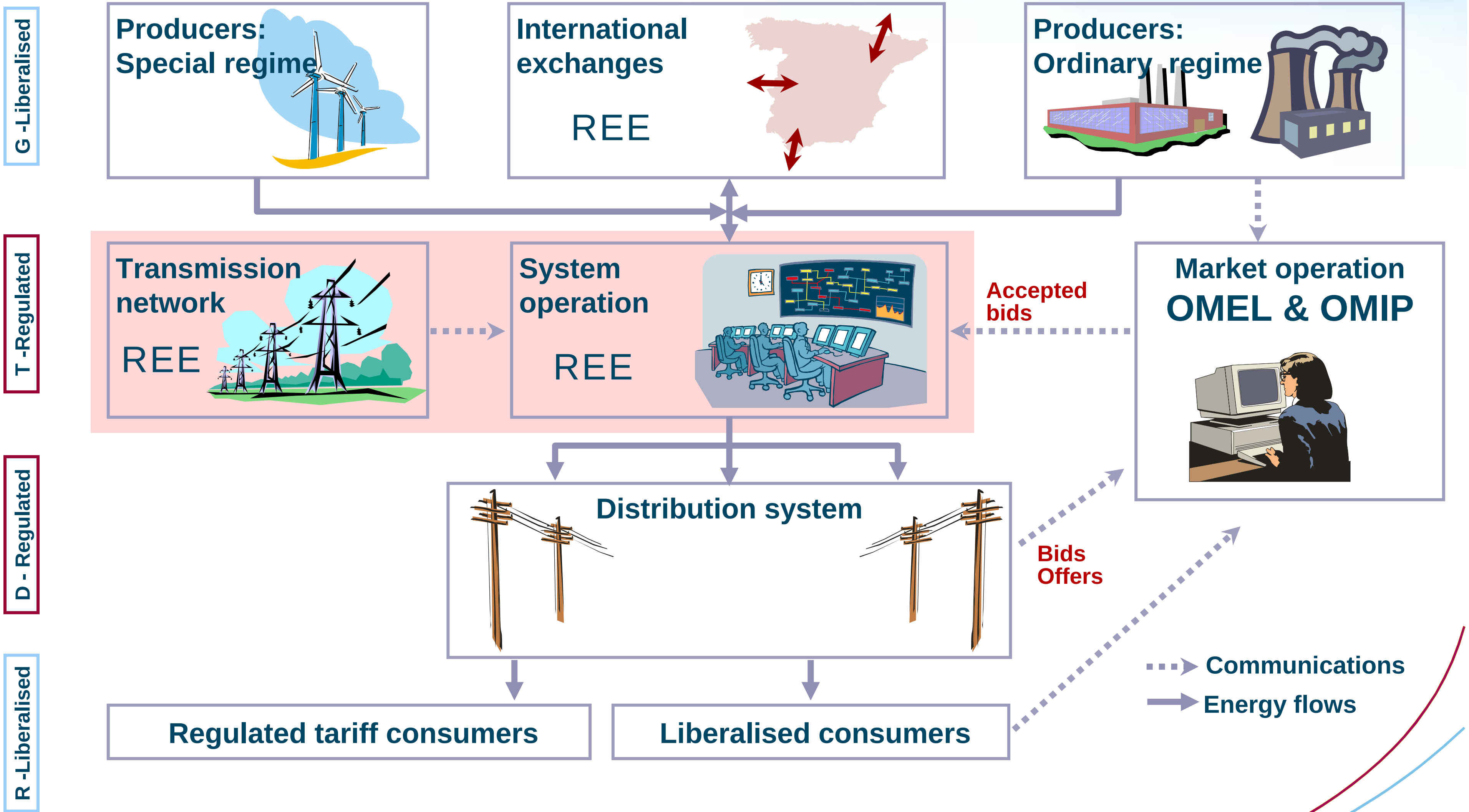
Conclusions

Integration in the European Interconnected Power System



Source: EURELECTRIC(2005) & REE (2006)

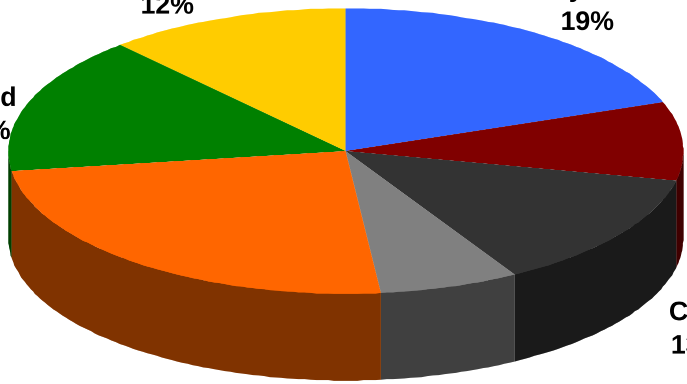
Spanish electric sector organisation



Installed Capacity and Supplied Energy 2007

(without Spanish islands)

Installed Power (MW)

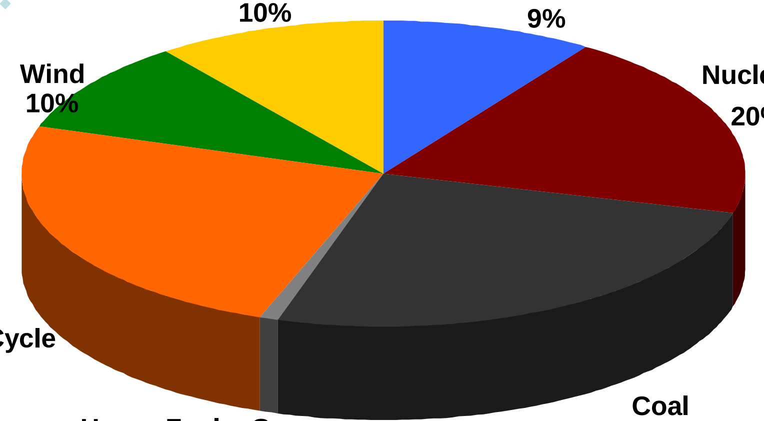


Installed Power: 85,959 MW
Ordinary Regime: 62,580 MW
Special Regime: 23,380 MW

Peak demand: 44,876 MW
(17th December 2007, 19h-20h)

(Special Regime Generation includes mainly cogeneration, small hydraulic, wind, biomass and solar energy)

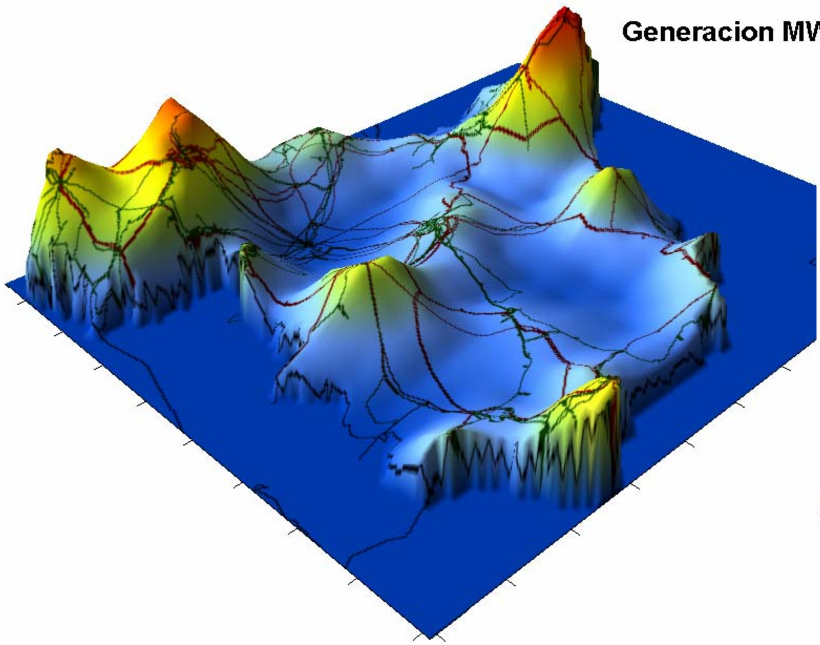
Supplied energy (GWh)



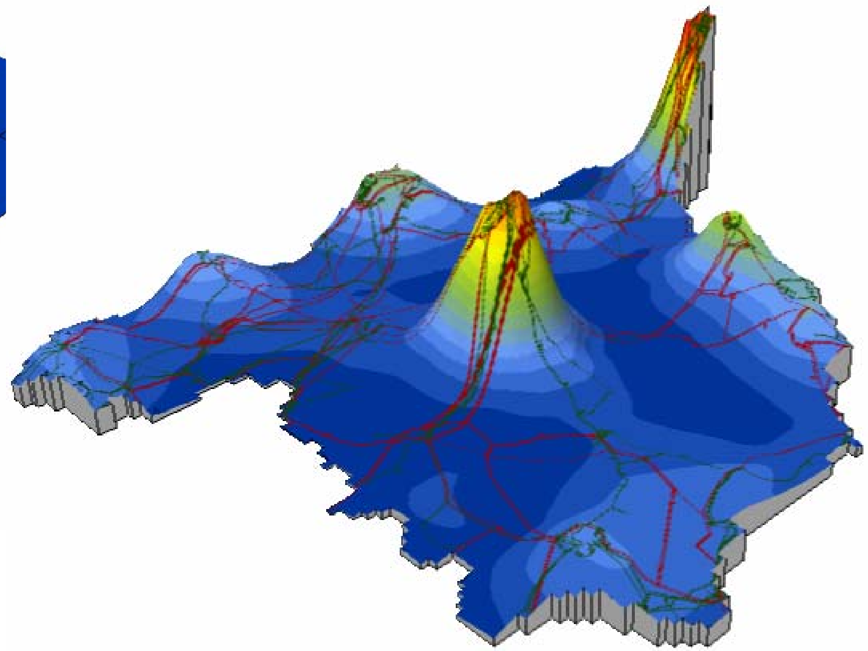
Ordinary Regime: 223,962 GWh
Special Regime: 55,754 GWh
Interchanges: -5,803 GWh

Generation and Demand distribution

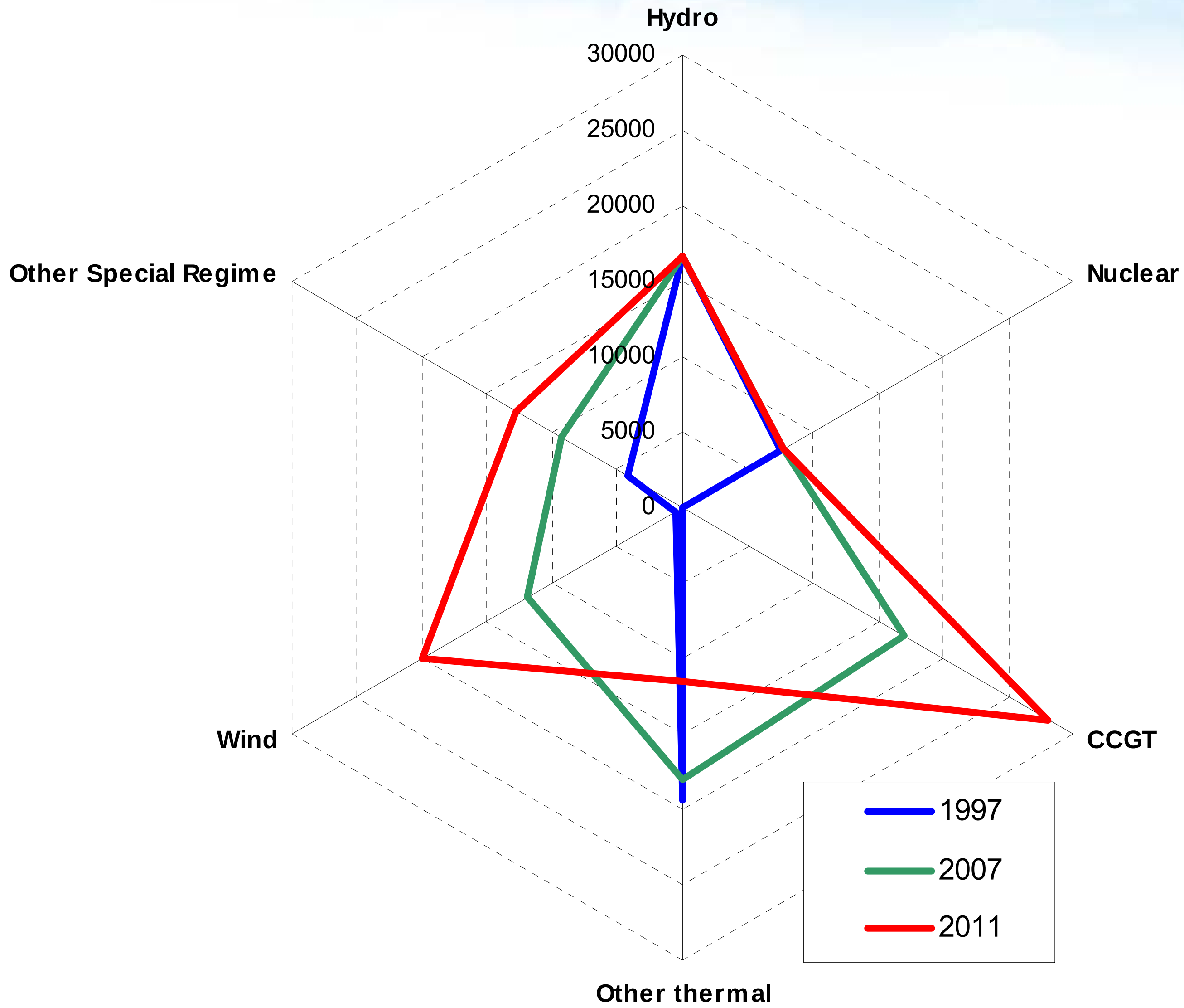
Generation



Load

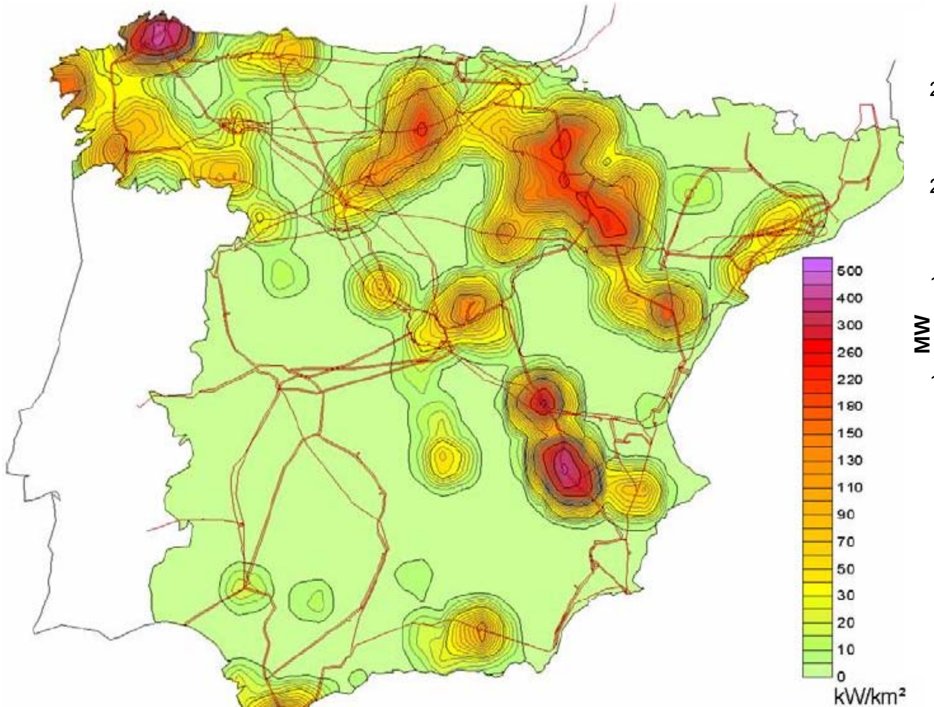


Spanish Peninsular Power System: Installed power by technology

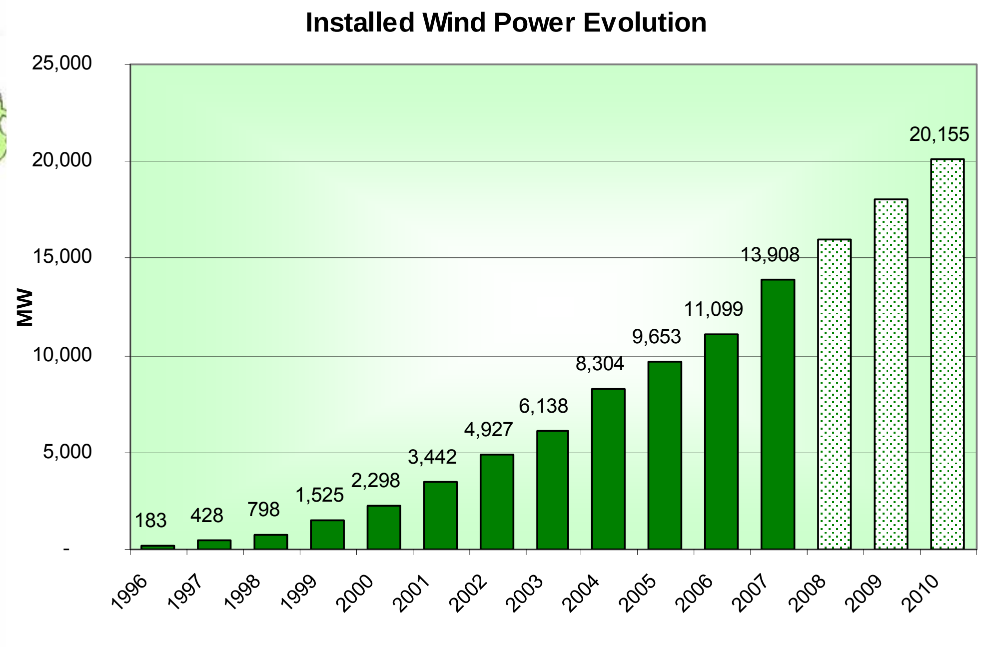


Typical Wind Farm configuration

Wind Power Capacity and Evolution



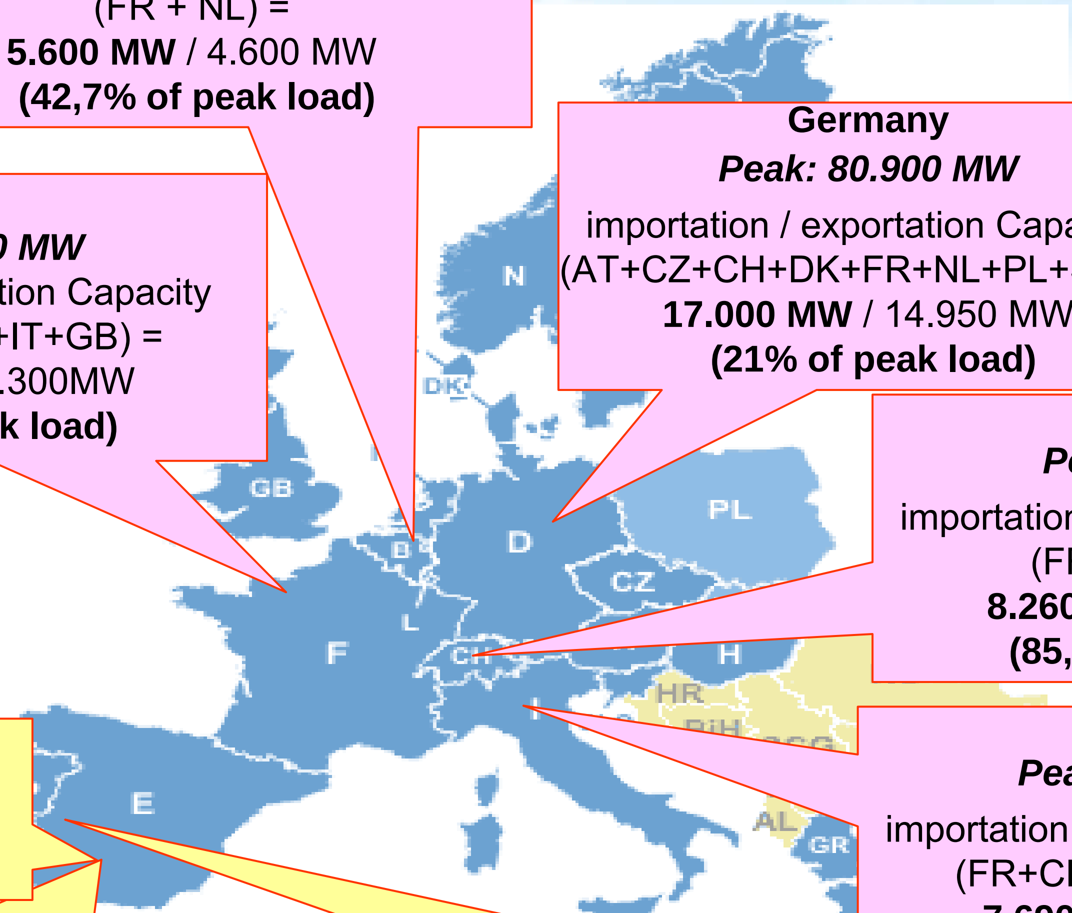
Installed Wind Capacity April 2008



(April 2008: 14,875 MW)

Spanish Renewable Energies Plan (August 2005): ~20,000 MW by the year 2010
RD 661/2007: 20,155 MW (85%) for bonus and additional 2,000MW for repowering

Singularities of the Spanish Peninsular Power System



Belgium

Peak: 13.100 MW

importation / exportation Capacity (FR + NL) =

5.600 MW / 4.600 MW

(42,7% of peak load)

France

Peak: 86.300 MW

importation / exportation Capacity (BE+DE+ES+CH+IT+GB) =

11.300 MW / 18.300MW

(13,1% of peak load)

Germany

Peak: 80.900 MW

importation / exportation Capacity. (AT+CZ+CH+DK+FR+NL+PL+SE) =

17.000 MW / 14.950 MW

(21% of peak load)

Switzerland

Peak: 9.700 MW

importation / exportation Capacity. (FR+DE+IT+AT) =

8.260 MW / 11.390 MW

(85,1% of peak load)

Italy

Peak: 54.100 MW

importation / exportation Capacity. (FR+CH+AT+SLO+GR) =

7.690 MW / 3.200 MW

(14,2% of peak load

Spain
importation Capacity.
FR: 1.400 MW **(3,3%D_p)**
PT: 1.200 MW (2,8%D_p)

Spain

Peak: 43.400 MW

importation / exportation Capacity (FR+PT) =

2.600 MW (6% D_p) / 1.800 MW

Iberian Peninsula (ES+PT)

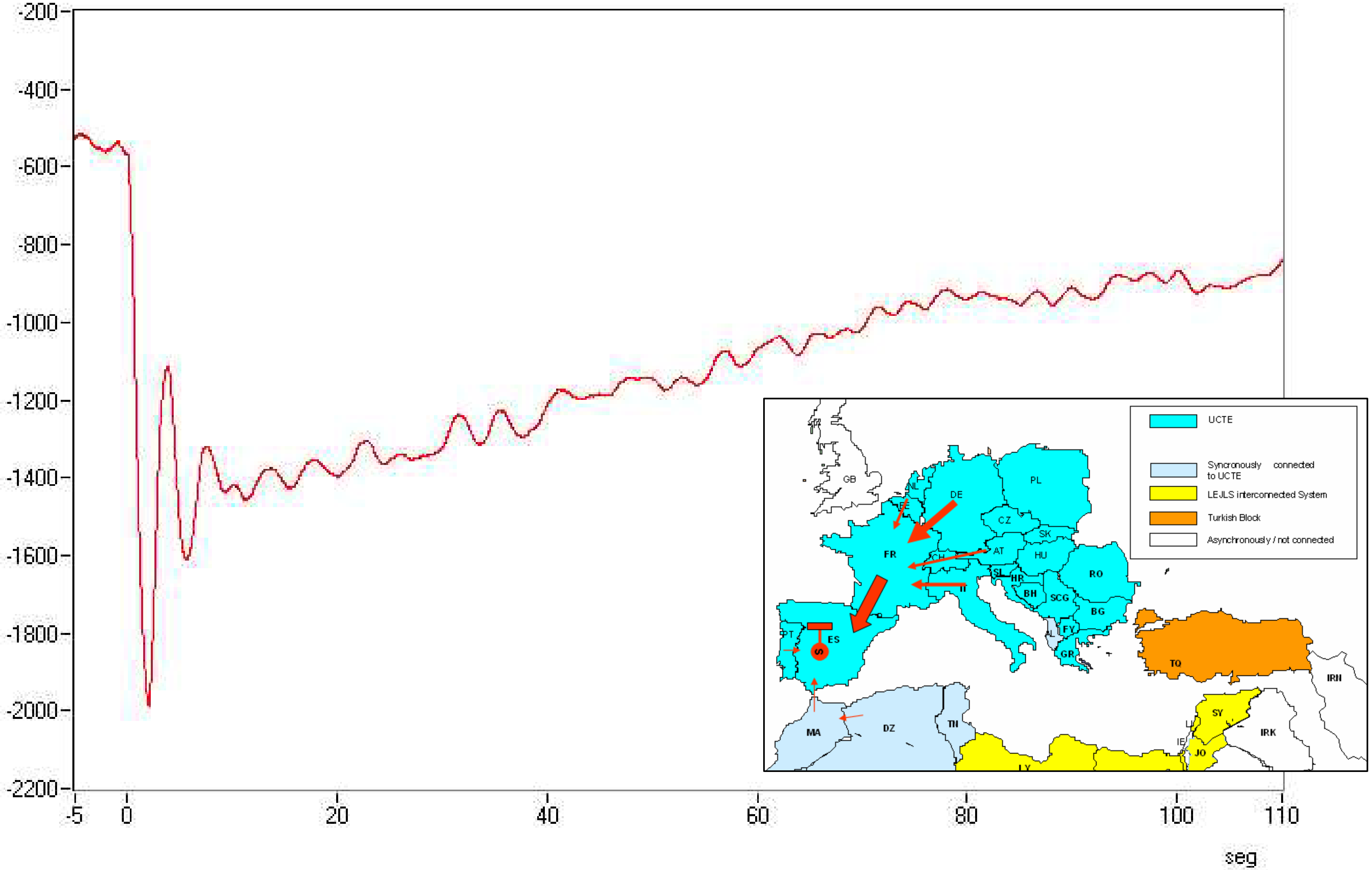
Peak: 52.000 MW

importation / exportation Capacity. ***(UCTE)*** (FR) = **1.400 MW** / 500 MW

(2,7% of peak load)

- **2006/2007 Winter Net Transfer Capacities (www.etso-net.org & www.ree.es)**
- **Peak load (www.ucte.org and TSOs)**

Typical Dynamic response



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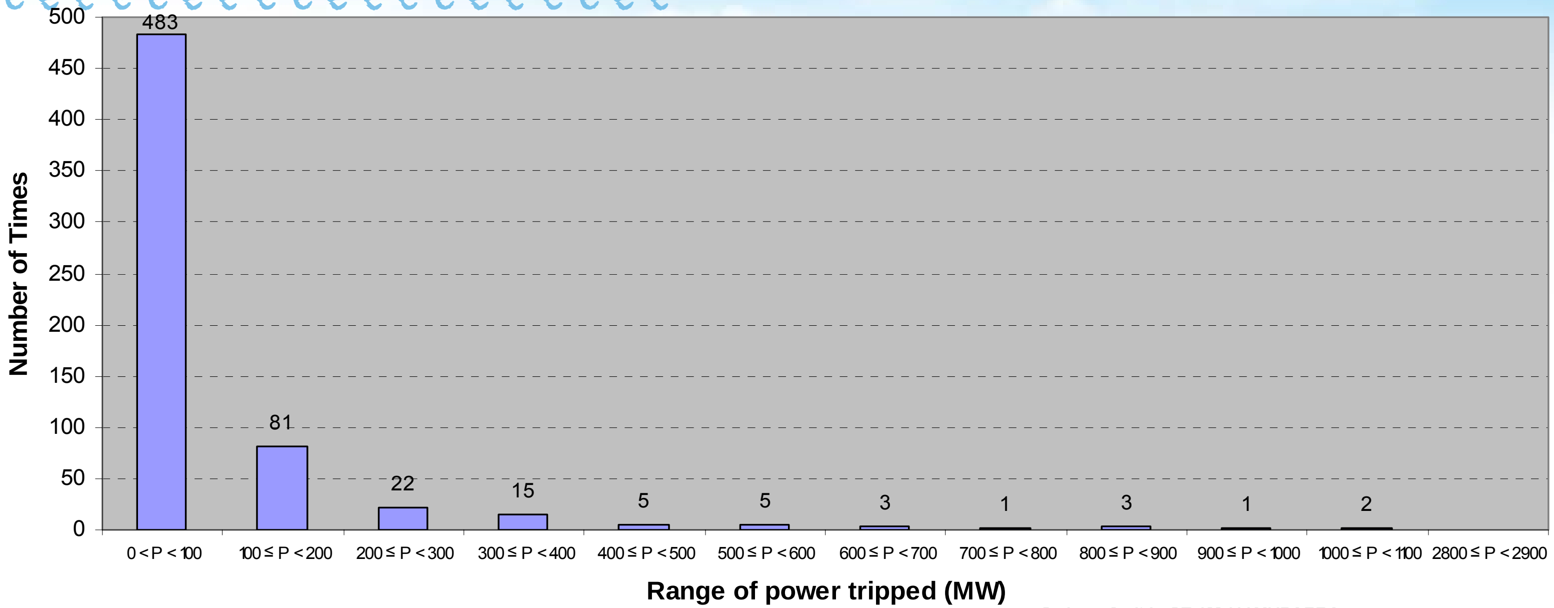
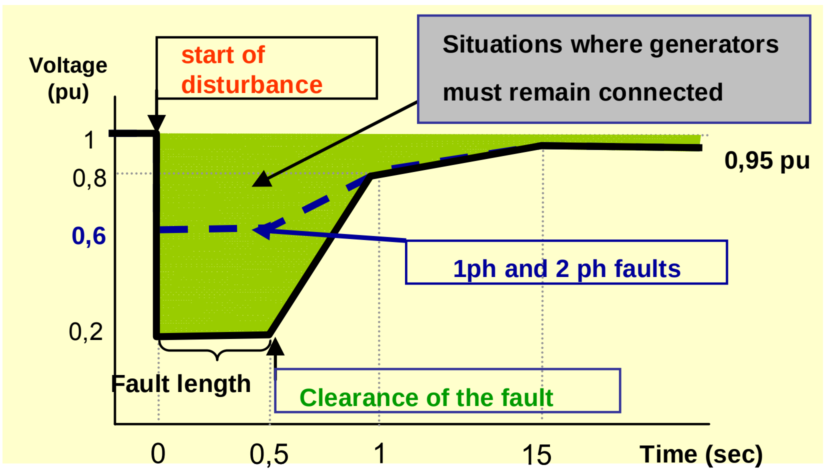
Problematic issues for a TSO

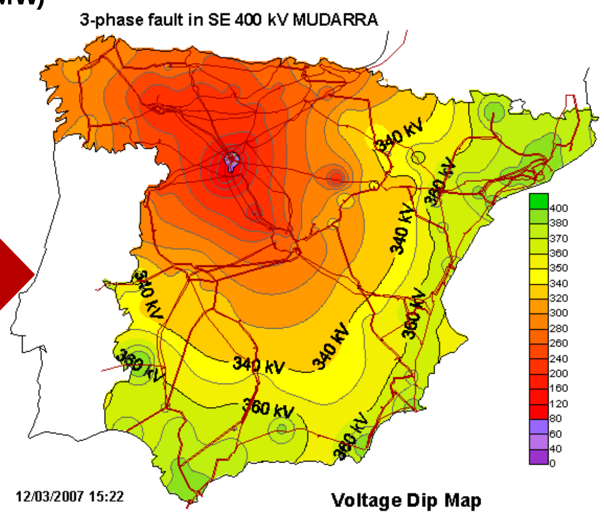
1- Regional plans and access request (H2011): 39.479 MW	Transmission system
2- Transmission Network developments: Evacuation studies	
3- Fault-ride-through capability	electric System
4- Reactive power control	
5- Short-circuit currents	
6- High forecast errors	system Operation
7- Wind power volatility (load curve up droop and down droop)	
8- Contribution to demand coverage	

3- Fault-ride-through capability



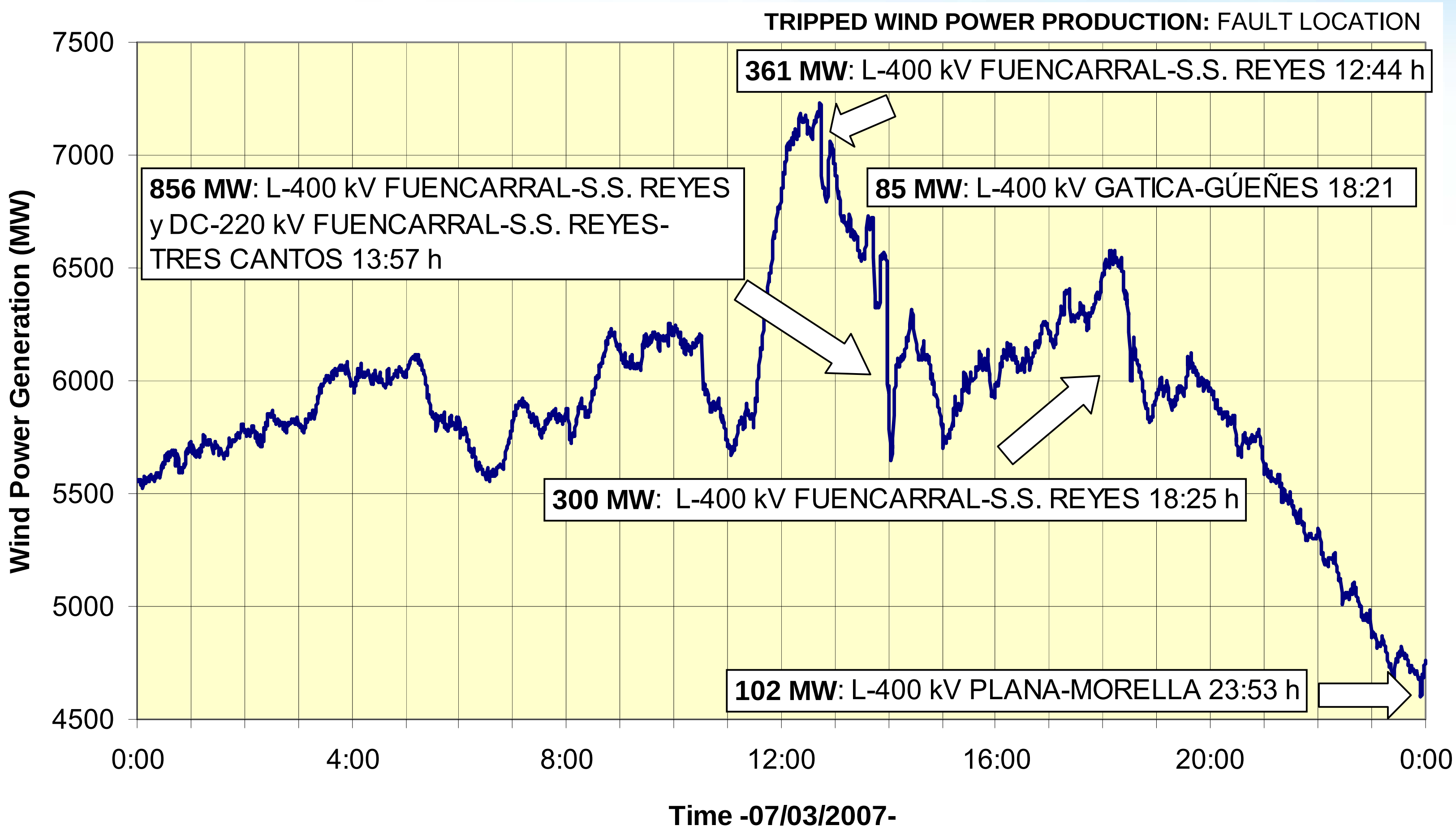


New "grid code". Operational Procedure 12.3



Real Time Risk Assessment

3- Behaviour during voltage dips

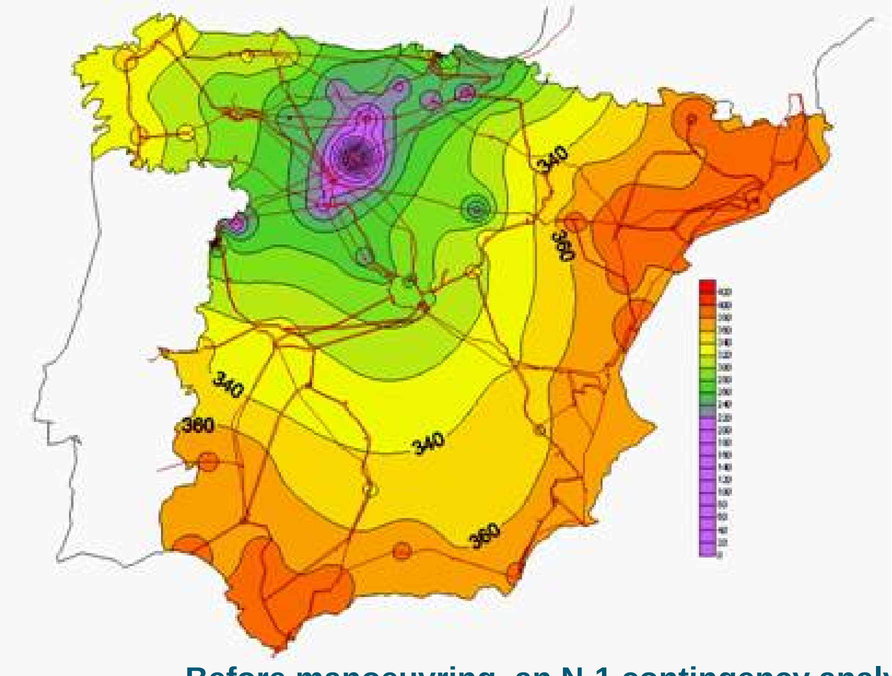


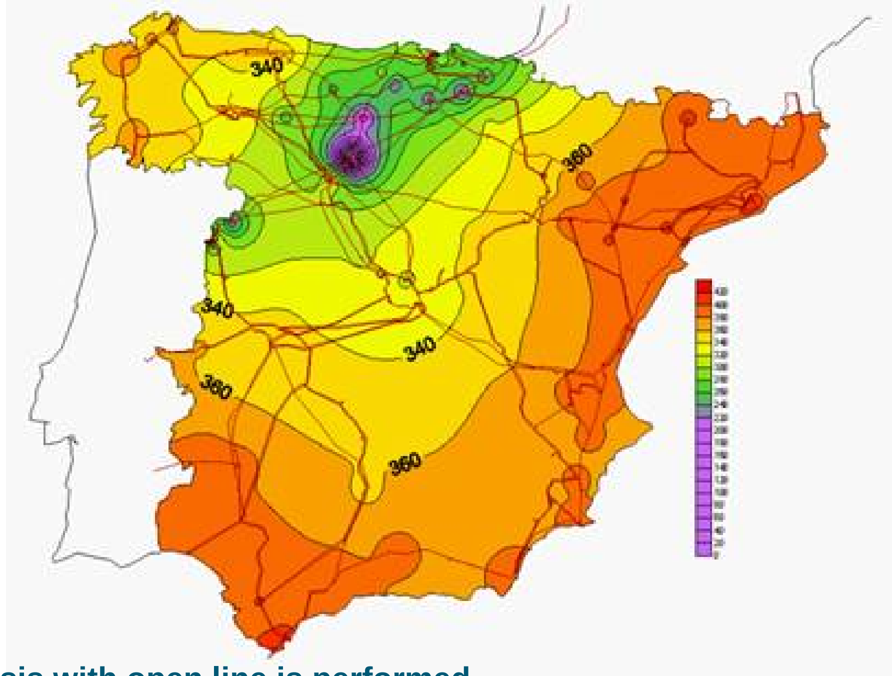
60% of the installed wind turbines have no fault-ride-through capability for faults shorter than 100ms and voltages dips under 85% p.u.

3- Topological measures to avoid wind power reduction

- Objective: Reduce possible loss of wind power generation trying to avoid preventive reduction of production (over 1.300 MW with full occupation of France-Spain capacity)
- Disadvantages: only in some cases and affects grid reliability

Line opening reduces maximum wind power loss after Short Circuit
2.386 MW → 1.451 MW (situation with 5.000 MW national production)



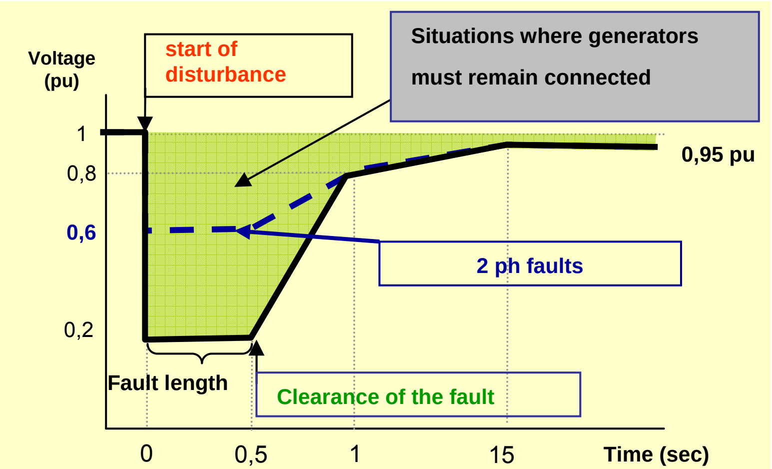


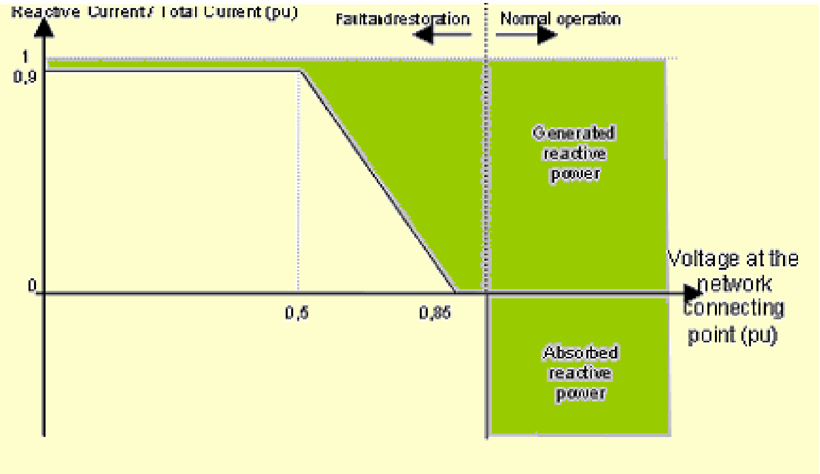
Before manoeuvring, an N-1 contingency analysis with open line is performed

3- New regulation for special regime generation

- A new grid code for wind generation has been approved to assure voltage dip ride-through capabilities for all new wind farms. Existing farms have several years to retrofit. PO 12.3.

New “grid code”. Operational Procedure 12.3

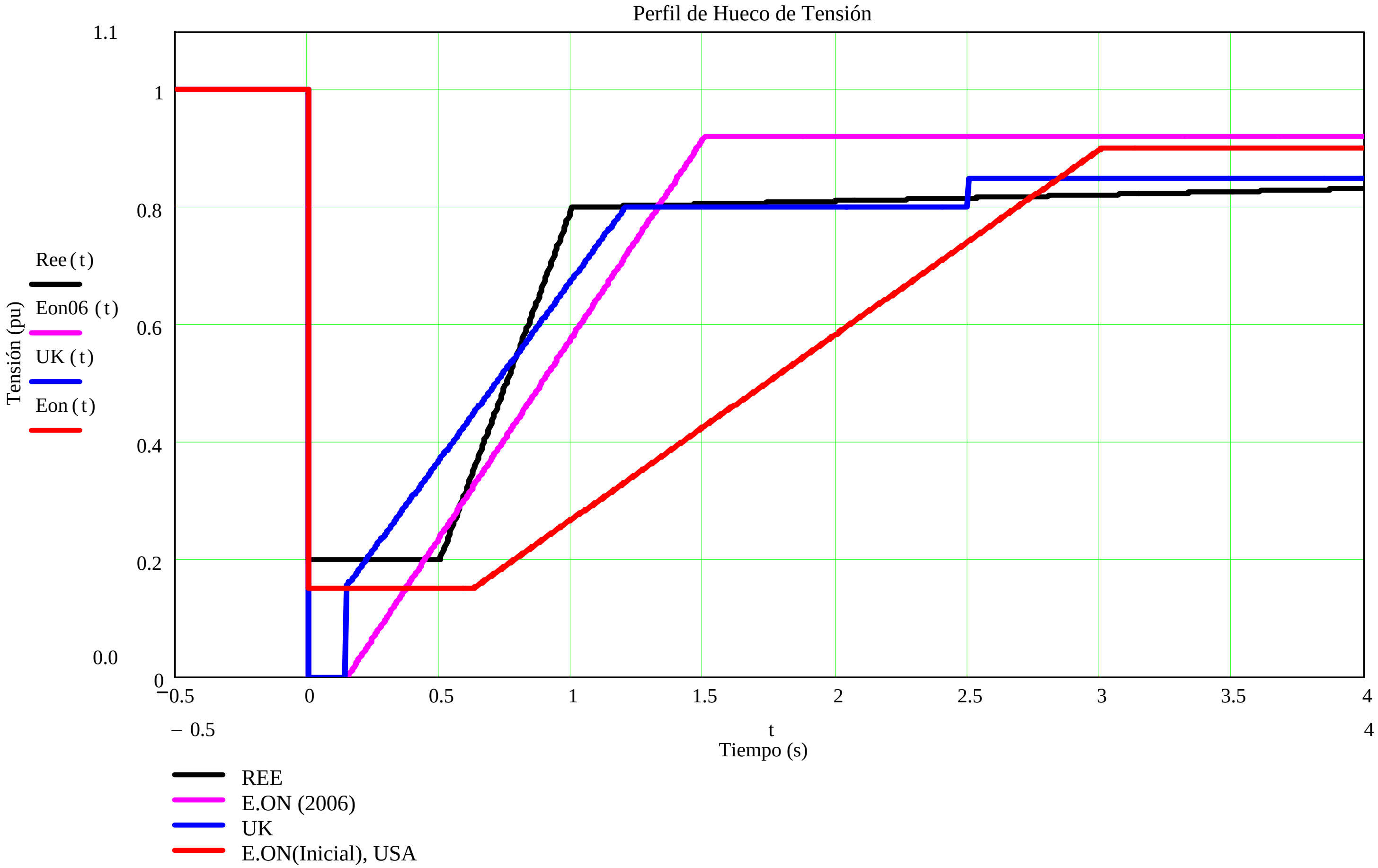




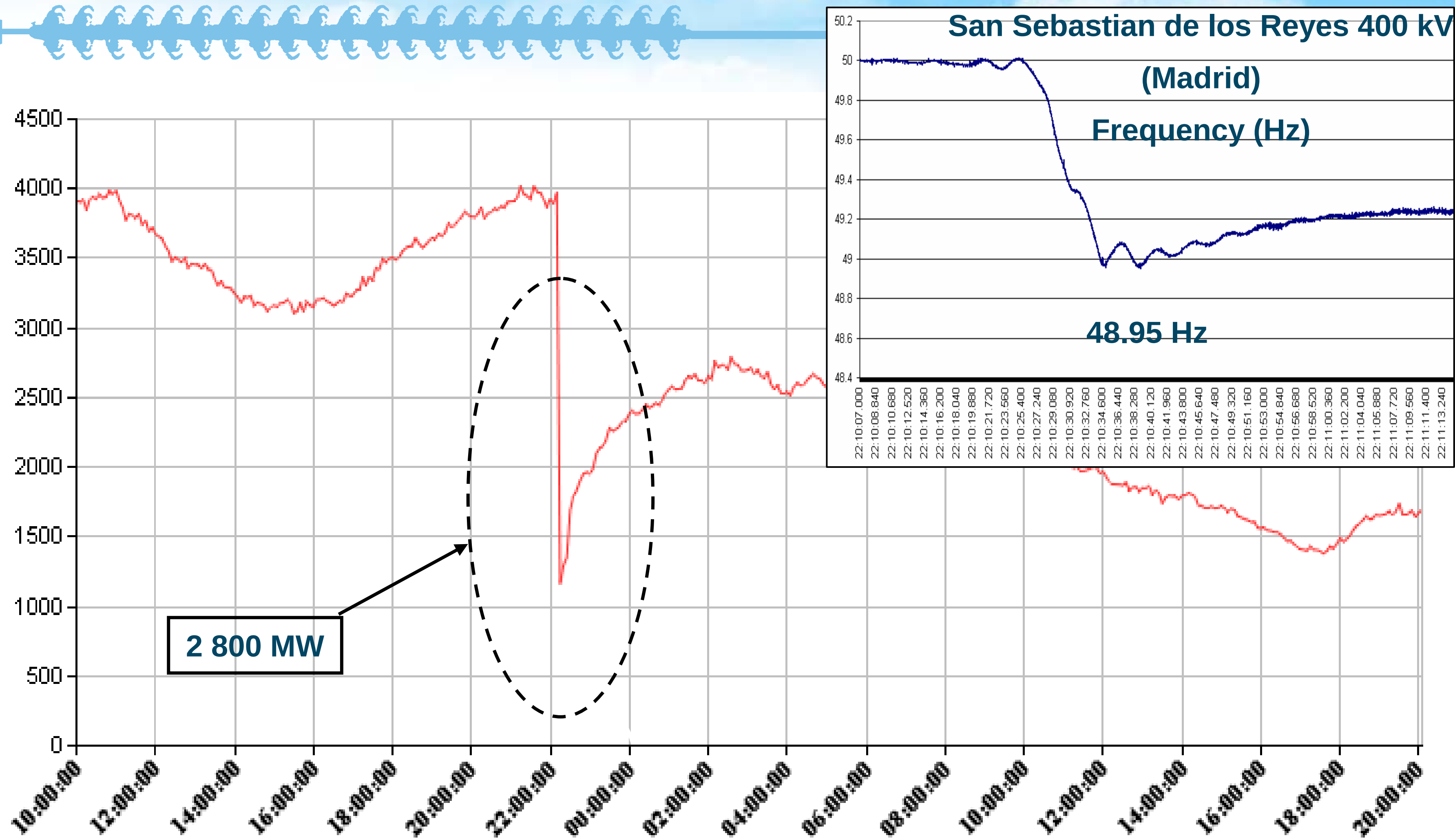
- Limits in power consumption (P,Q) during the fault and recovery: exception periods - ≈150 ms- and lower restriction for unbalanced faults

- Establishment of a certification process that ensures fault-ride-through requirements

Voltage dips in International grid codes



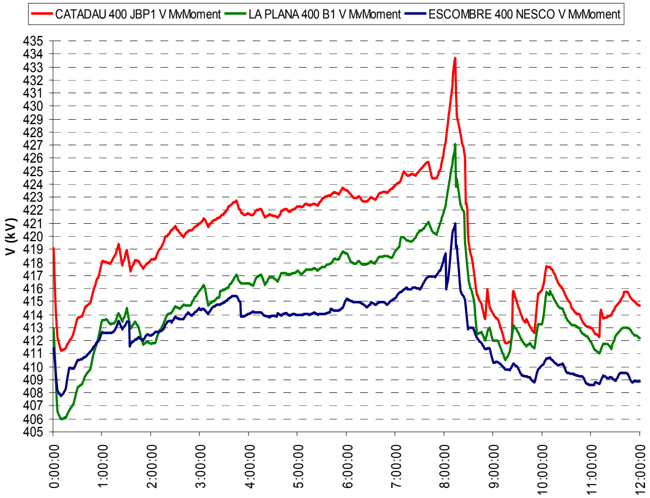
3- Frequency dips: 4th Nov. 2006

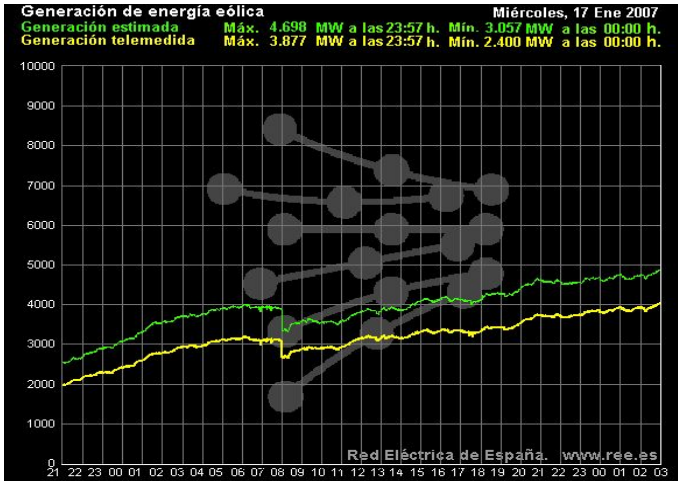


- New regulation allows disconnection only if frequency drops below 48 Hz for over 3 sec.
- No disconnection until 51 Hz

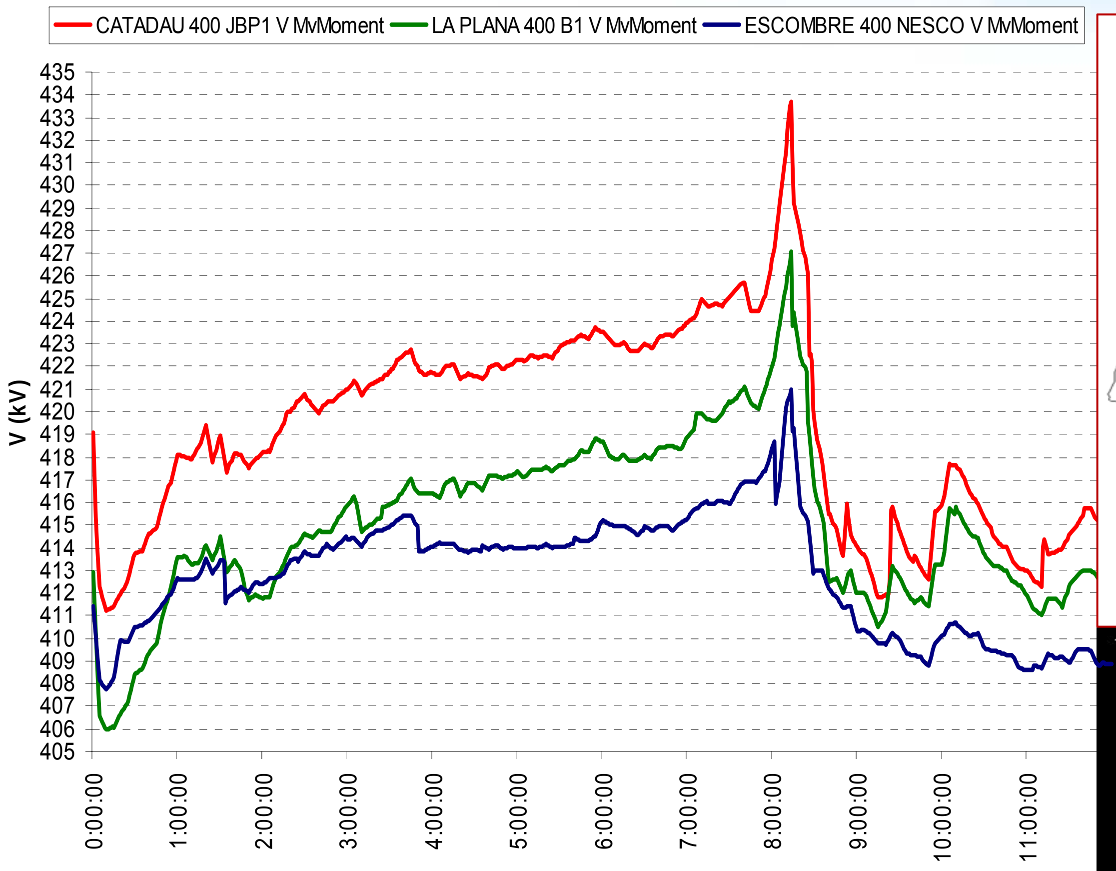
4- Voltage Control

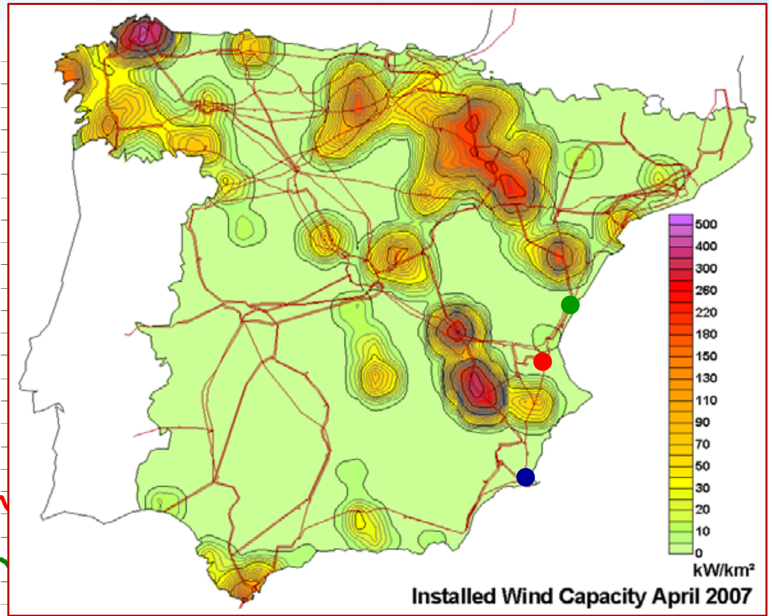
- Voltages must be kept within specific margins despite variations in the conditions of the system: demand, power flows, online units etc.
- Besides System Operator’s manoeuvres, the system needs contribution from online generators (reactive power)
- At present, wind generators receive an additional bonus according to a table (RD 661/2007) with hourly power factors. This solution is also a problem due to simultaneous change of power factors which causes deep voltage variations (and consequent disconnections)
- They can receive instructions from the System Operator with the maximum bonus

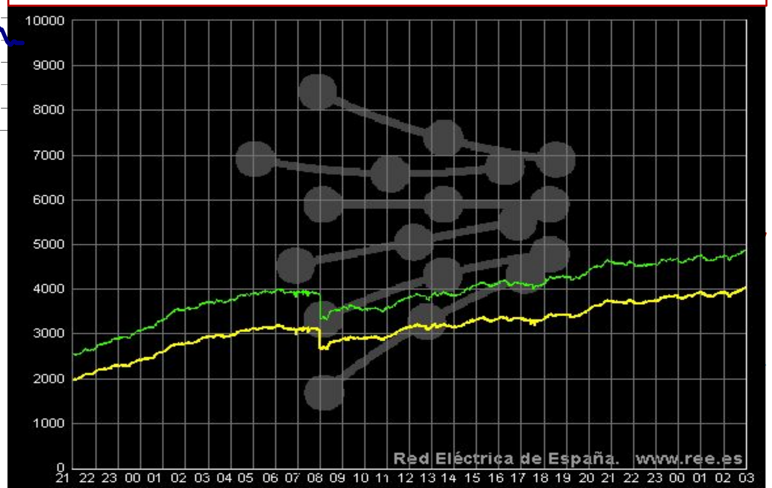




4- Voltage Variations on April 6^{th} 2007







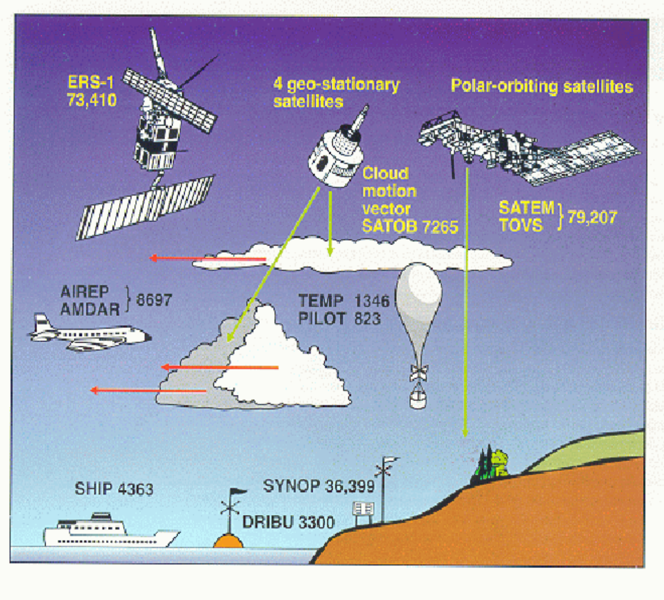
5- Short circuit currents

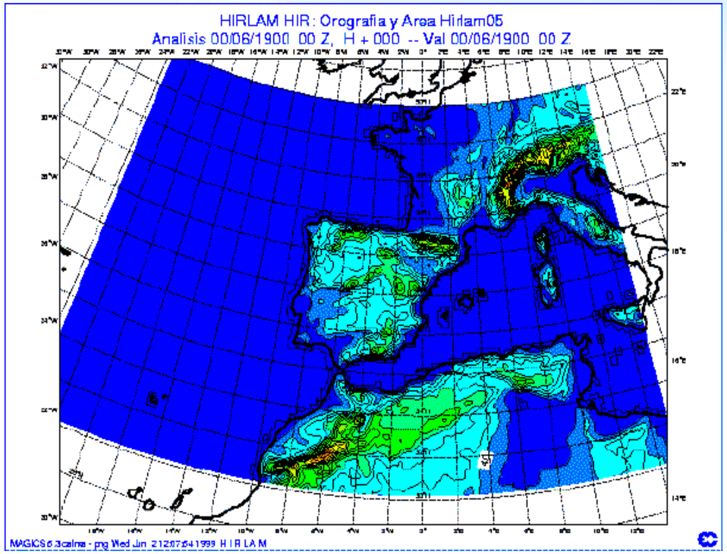
- Short circuit power is needed to detect faults in the system
- Wind generators present low short-circuit power and inertia is ‘hidden’ to the electric system; they reduce system inertia (oscillation modes)
- They displace conventional generators with large short-circuit power from the demand coverage, reducing the ‘strength’ of the node (wave quality: voltage variations, harmonics, flicker)
- Limiting the installation of wind generators according to node short-circuit power ensures system security and wind power dispersion over the territory

6- Wind production forecast: "SIPREOLICO" model

- Developed by REE with the University Carlos III of Madrid
  - Project began in 2001
  - Prototype by December 2001, operation since 2002
  - Developed in MATLAB
  - Permanent improvements going on
- Needed to replace previous individual forecasts from wind farms
  - D-1 contingency and security analysis
  - Analysis of reserve margins
  - Intraday balancing markets
  - Real time operation

6- Wind production forecast: "SIPREOLICO" model





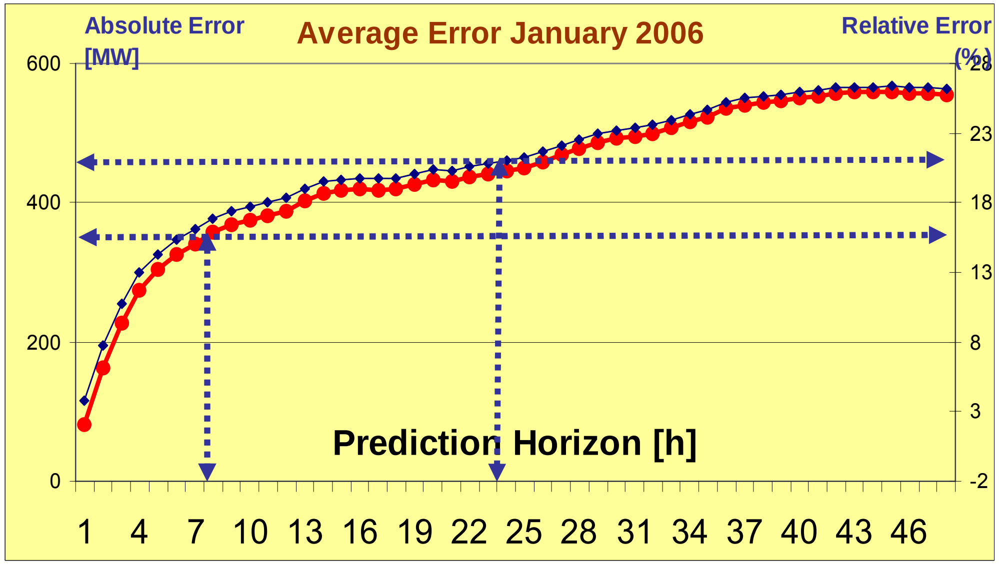
- Forecast of wind speed (HIRLAM Model)
- Information of wind farm characteristics
- Curves Power .vs. Wind speed
- Real time data
- Historic data

Algorithms

- Every 15 minutes hourly forecast for up to **24 - 48 h**
- Global and individual production forecasts
- Statistical treatment of two algorithms
- Provides expected values, plus probabilistic exceedance intervals

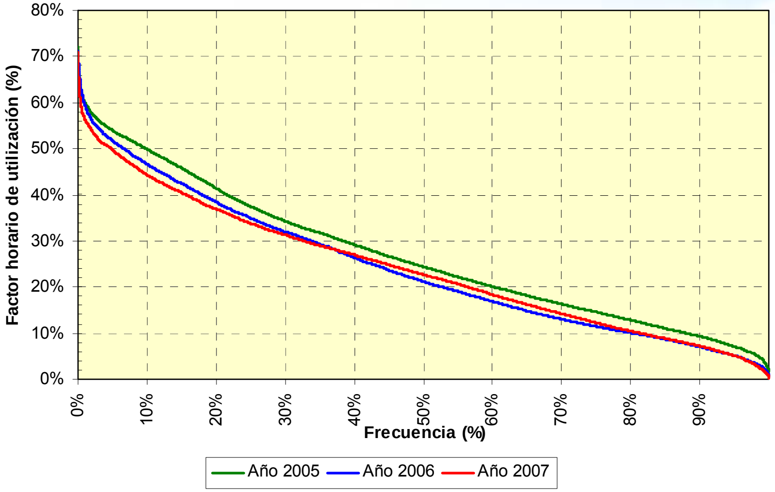
6- Wind production forecast: “SIPREOLICO” model

- Responsibility of the forecaster is to provide the best forecast. With it, the System Operator must
  - Analyse accuracy of the forecast
  - Analyse the behaviour of the wind
  - Anticipate and prevent risks caused by forecast errors and ‘undesired’ wind behaviours
  - Ensure that with its balancing mechanisms and their operating times, system will not be at risk in real time

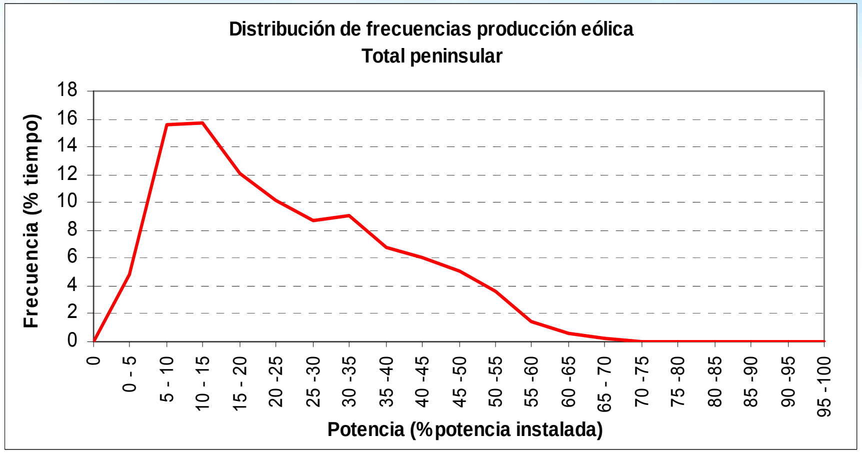


- Mean relative error of ~20% for 24h forecast
- Normalised mean square error of ~5% for 24h forecast

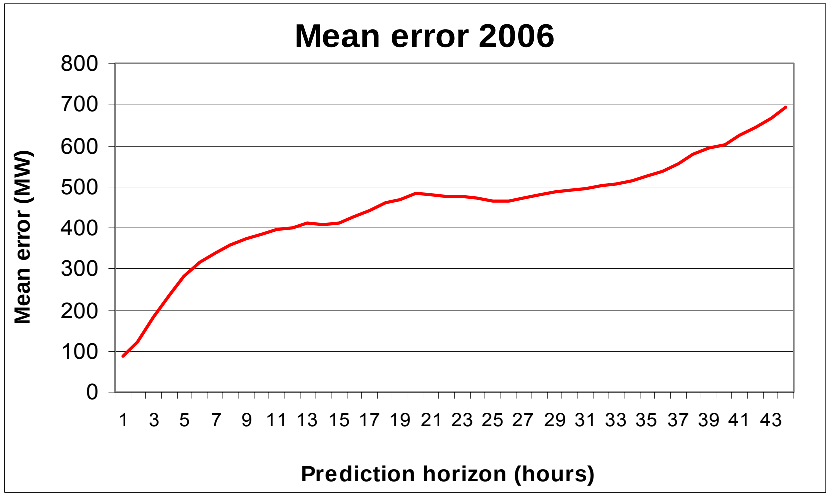
6- Wind production forecast: "SIPREOLICO" model



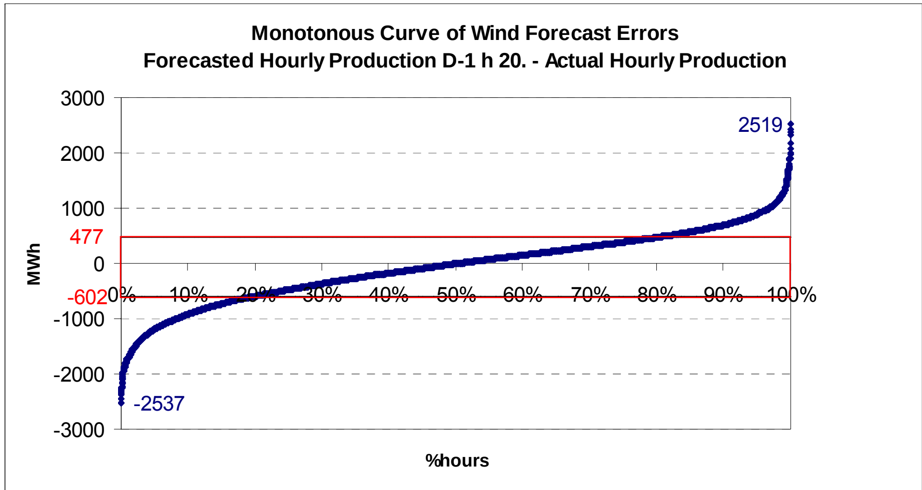
Wind duration curves



Production probability distribution, 2006

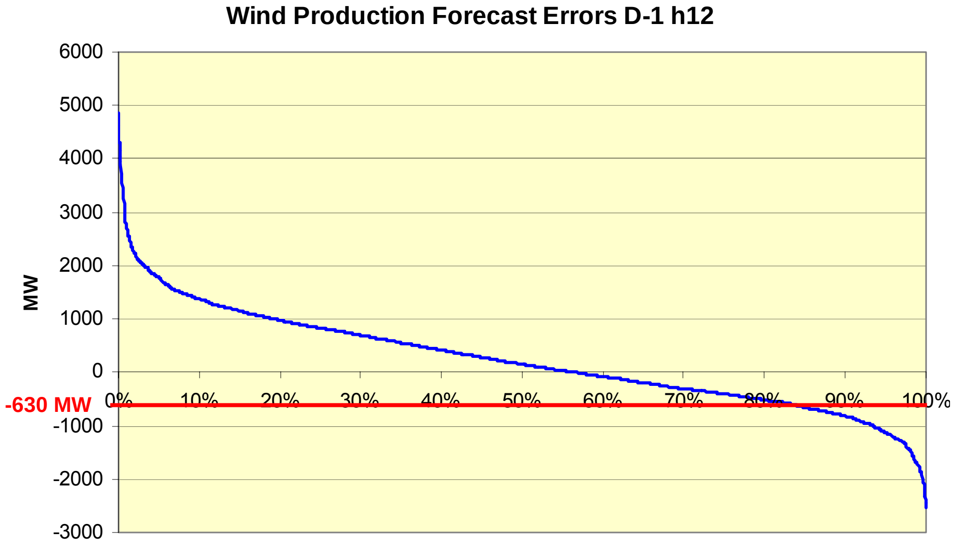


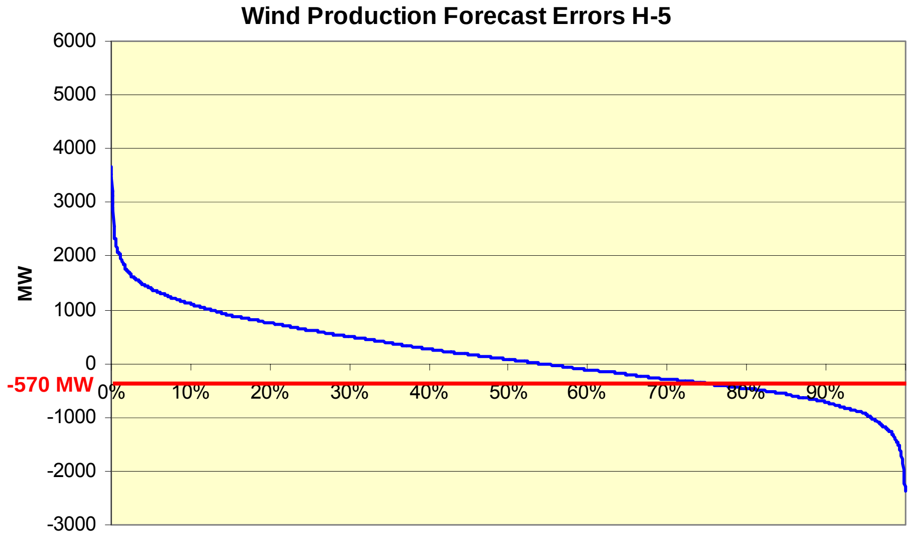
Mean absolute error



absolute error duration curve

Impact of forecast errors in the demand coverage





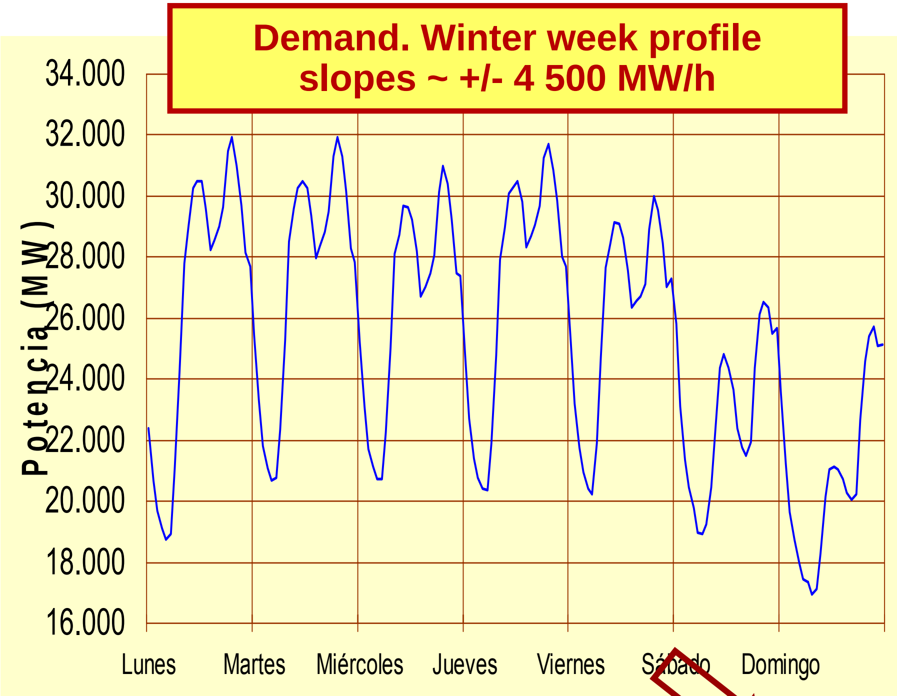
- In D-1 at hour 12 when the daily congestion management studies are conducted there is a 15% possibility that wind production is 630 MW lower than predicted.
- Within start-up time of thermal power units (5 hours in advance) there is still a 15% possibility that wind production is 570 MW lower than predicted.
- Reserves are checked within these time scopes and the uncertainties must be translated into further running reserves. Additional thermal groups might be needed to guarantee demand coverage.

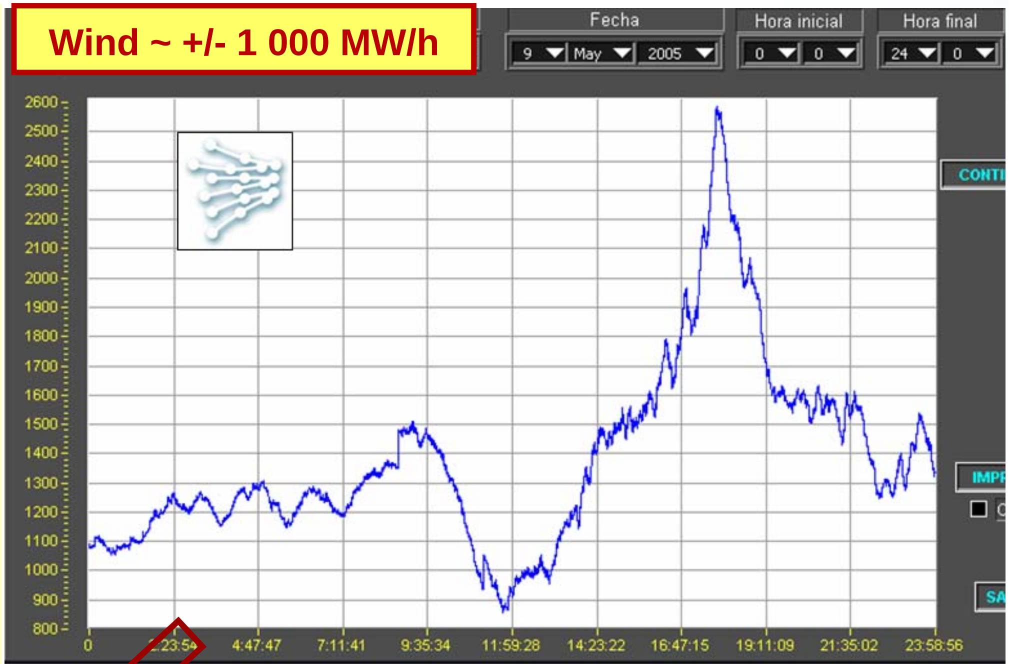
Impact of forecast errors in the demand coverage

- Forecast errors introduce uncertainties (as well as the demand forecast).
- Spinning reserves are checked after day-ahead market and every intraday market. (the agents do part of the job adjusting their new positions in intraday market sessions)
- 60% of the time the error is smaller than 477 MW. These confidence values may be used to assure enough spinning reserve at all times.
- SOMETIMES more dispatchable generation needs to be coupled to the network (via 'constraints management' of the SO) during peak hours in order to substitute the possible decrease of wind power production
- The secondary reserve capacity is not higher. The use of secondary reserve energy is not significantly higher (instantaneous wind variations ~ demand variations)
- The wind variations (from their final program) moderately increase the system use of tertiary reserve and congestion management. (generation dispatched by SO in the day ahead market or in real time)

7- Variability of wind power and demand

- At national level: typical maximum increase/decrease slopes.





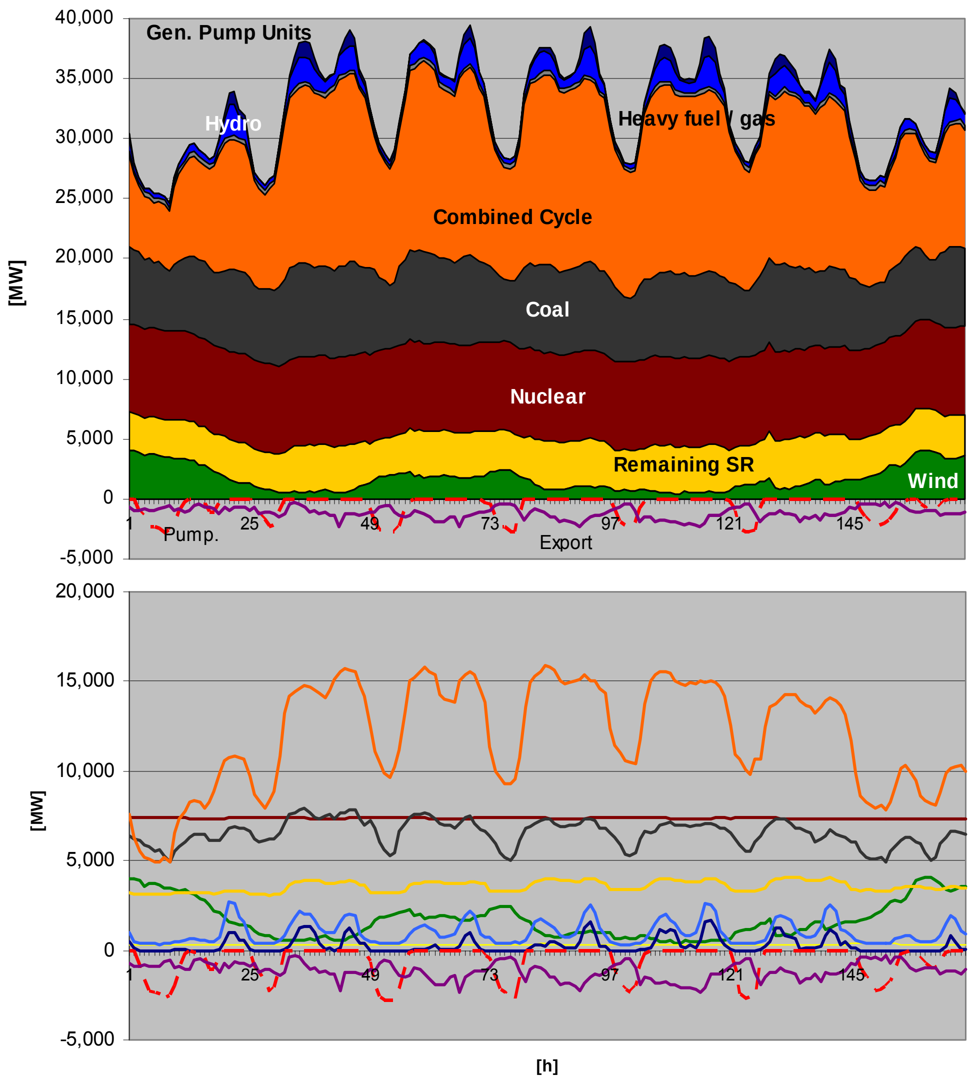
Demand + Wind: ~ +/- 5.500 MW/h (with < 10.000 MW inst of WP)

+ forecast error

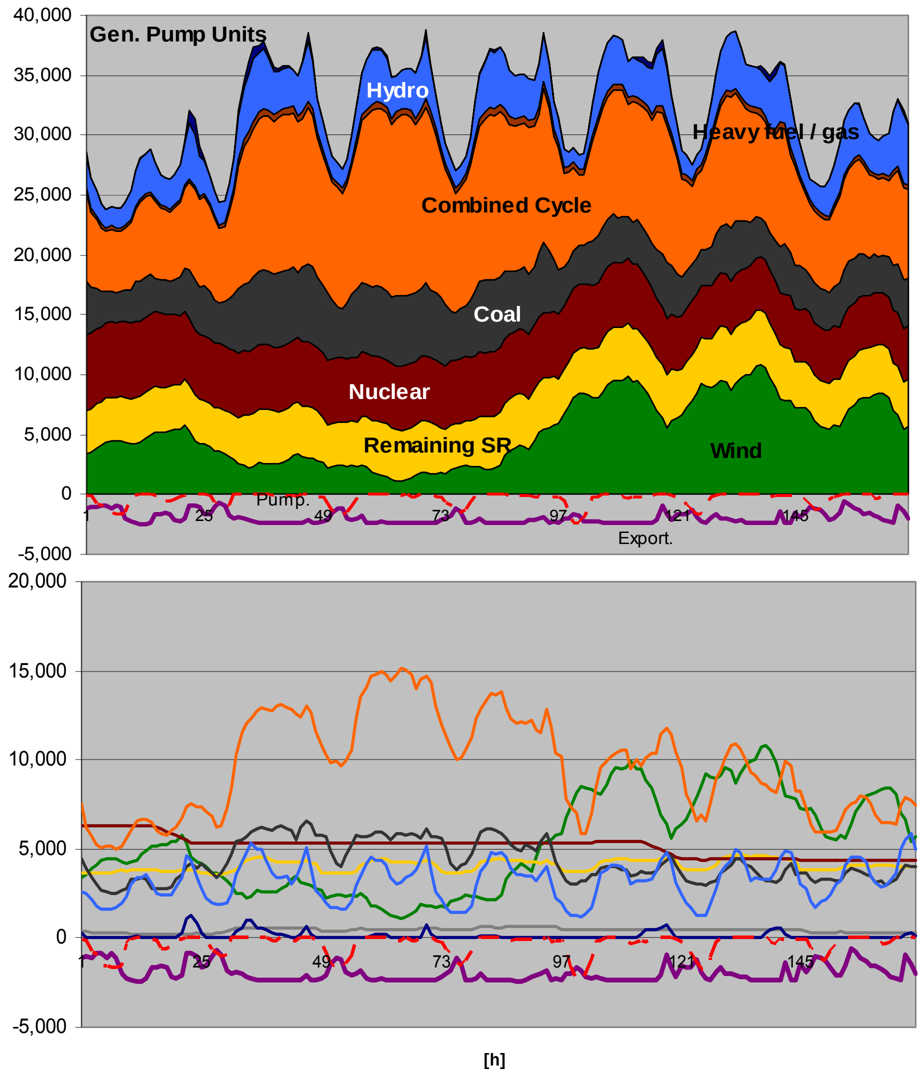
Will slopes be a limiting factor???

8- Contribution to demand coverage

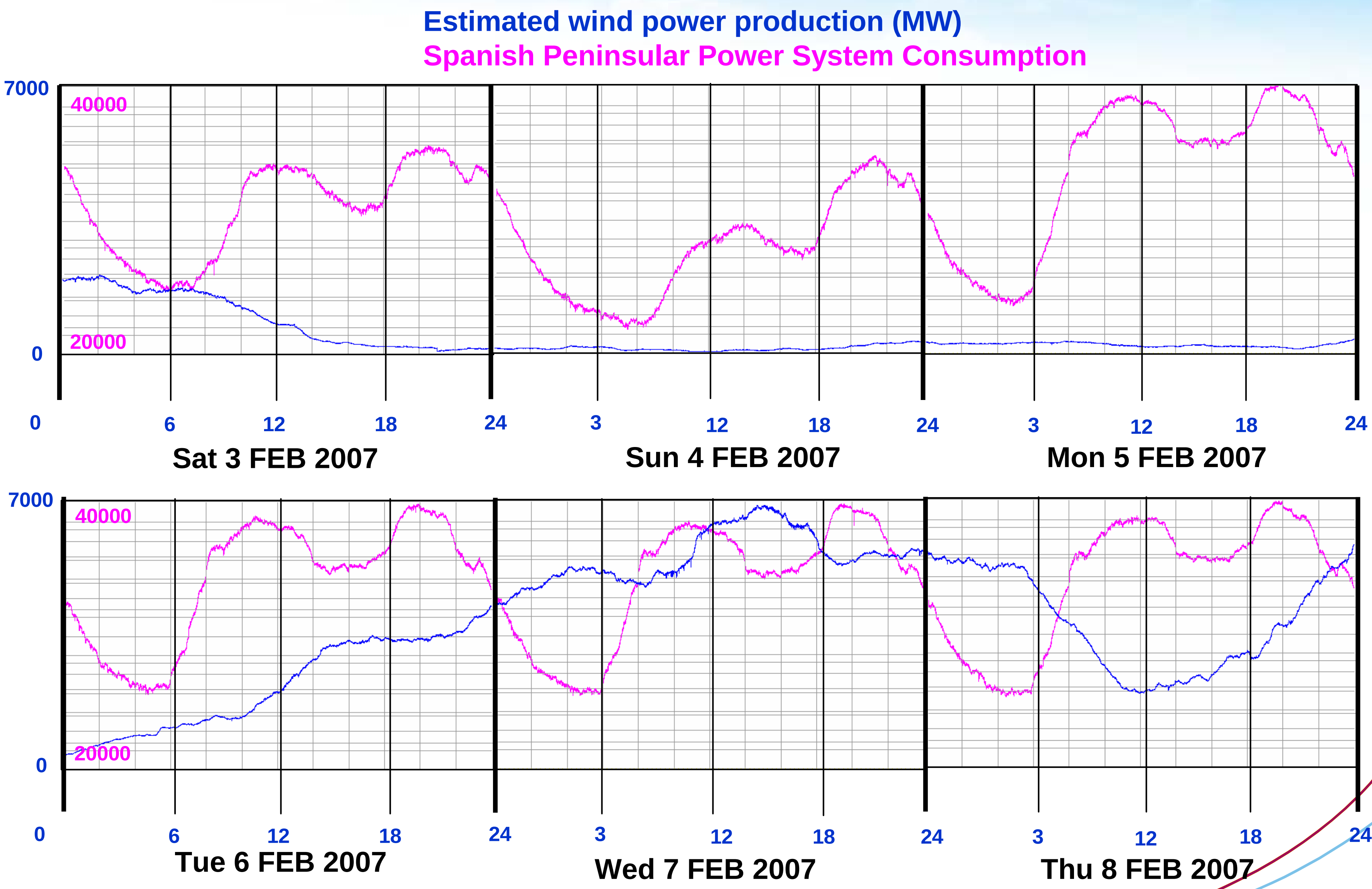
Spanish Demand Coverage - 24/02/2008 to 01/03/2008



Spanish Demand Coverage - 13/04/2008 to 19/04/2008



8- Contribution to demand coverage



8- Contribution to demand coverage

- **With such uncertainty … how much manageable installed power does the system need?**
  - **REE does not plan the generation**
  - **Multiple scenario testing**
  - **Little wind conditions must be considered for technical studies and generation and network planning, as well as high wind conditions –> higher cost of generation capacity and transmission capacity.**

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Maximum wind penetration studies

REE, CNE, Wind Associations (AEE y APPA), Spanish electricity companies and Portuguese REN

- **2011 scenario**
- **Network planning exercise**
- **Transient stability issues considered**
- **Definition of fault-ride-through requirements –> PO 12.3**
- **Definition of maximum wind power injection in the system ensuring system stability**

Study Results: dependence on the technical adaptation level*

16-20.000 MW inst

Case of demand	% of wind power technically adapted respect to the present one *(10GW)*	Admissible wind power production (MW)
Peak	50%	< 10.000 MW*
	75%	14.000 MW*
	100%	>16.000 MW*
Off-peak	0%	5.000 MW*
	75%	> 10.000 MW*

*Spanish Peninsular Power System

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Wind power integration

- Problematic issues for a TSO
- **REE solutions**

Maximum wind penetration studies

Control centre for renewable energies (CECRE)

Calculation of wind farm limitations (GEMAS)

Economic framework

Conclusions

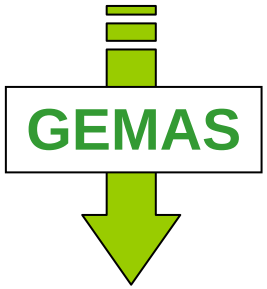
Control centre for renewable energies

- The large number of wind farms (~575) and grid nodes affected, as well as the development of company owned control centres, motivates that the system operation control needs are expected to be fulfilled by CECRE, as a dedicated centre for wind and in general for special regime:
  - Integrated within REE Control Structure
  - Mission: Maximise Special Regime integration, whilst ensuring system security. Real time Interlocution with generators
  - what for?:
    - monitoring required variables
    - issuing control instructions
  - how?
    - Permanent Situation: Communication via Wind Generation Control Centres. CECRE does not command or manoeuvre generation facilities; this task is carried out by ‘Wind Generation Control Centres’
    - Temporary Situation: Possible command function of CECRE as “last resource” control centre
- Issues concerning production control criteria defined by P.O. 3.7

Control centre for renewable energies

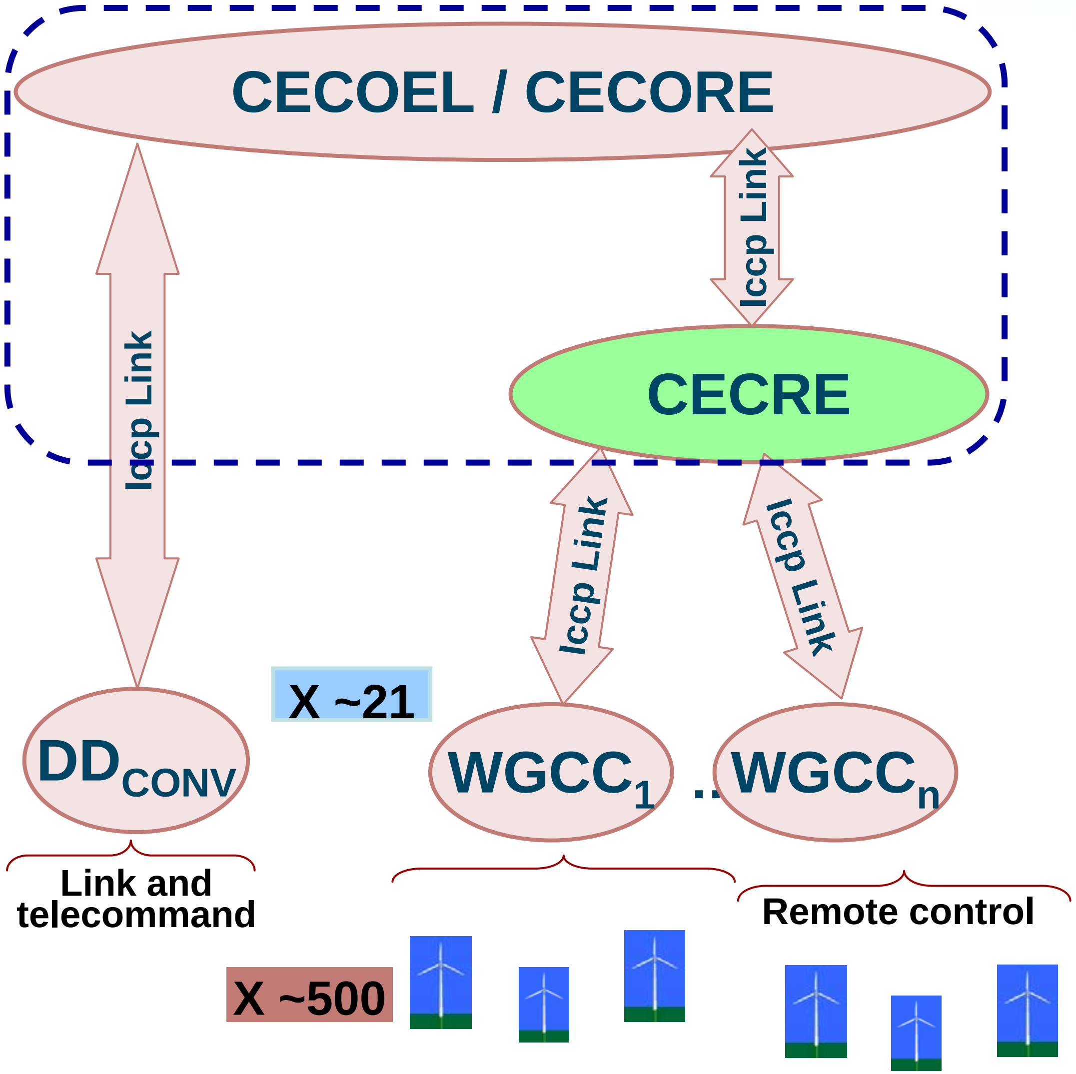
Control centre for renewable energies

- **Main function: achieve a greater level of integration for renewable energy sources without compromising system security**
  - **Improves security and effectiveness in system operation**
  - **Allows substitution of permanent preventive criteria for real time production control**



  - **Real time risk assessment due to voltage dip wind generation tripping**
  - **Wind production limitations calculation**
  - **Filter limits for solution stability and in accordance with legislation**

Functional scheme



CECRE is a control centre devoted to special regime generation and specially to Wind Power:

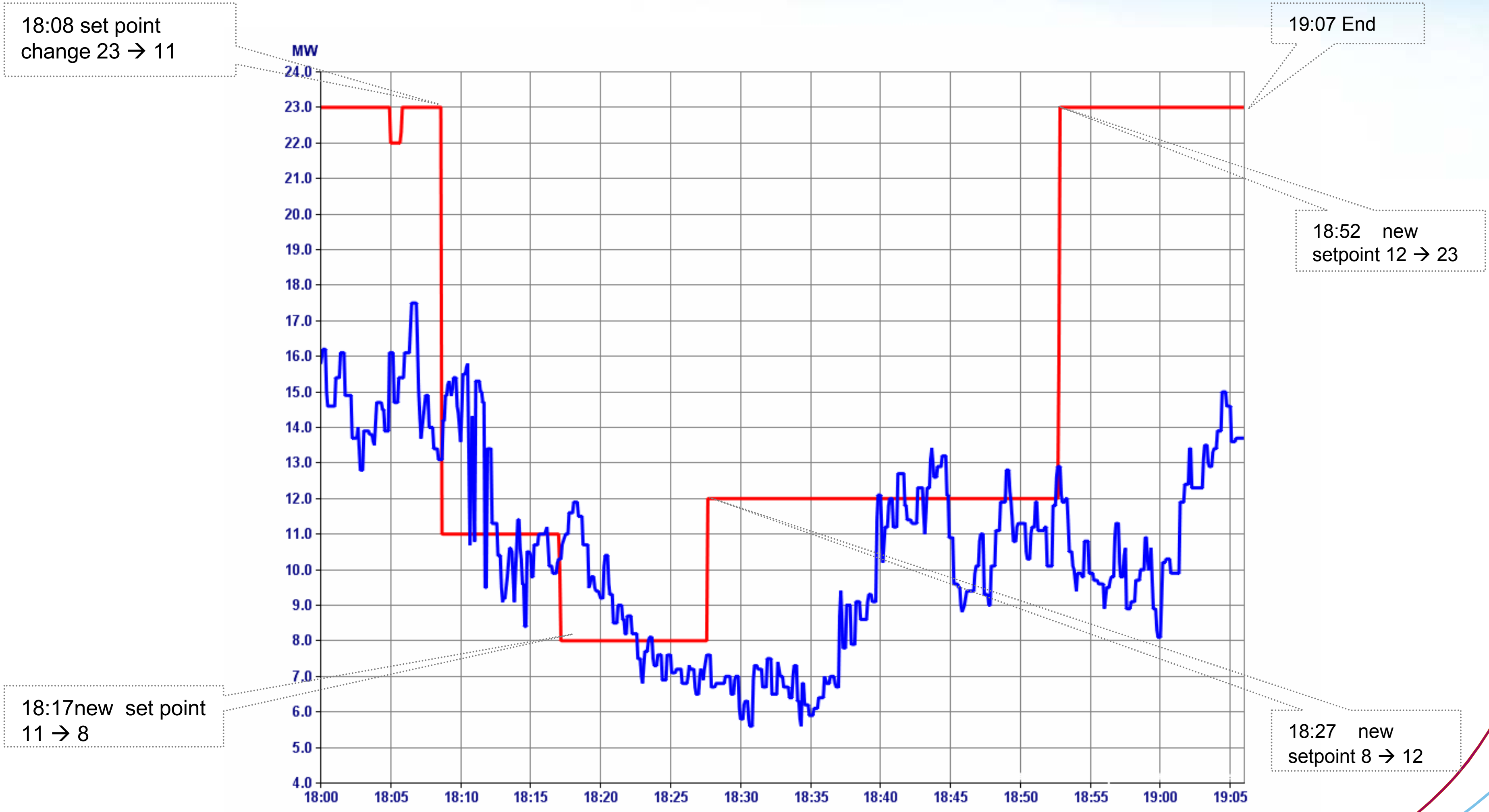
- Integrated in REE's control structure
- Communication with generation Control Centres for supervision and control instructions.
- CECRE does not telecommand generation equipment; this function is done by generation Control Centres.
- CECRE issues generation limitations through the SCADA system to the Control Centres.

WGCC: Wind Generation Control Centre

DD: Delegate Dispatch for conventional generation

- All power plants must associate to a Special Regime Control Centre before 30/06/2007 if P>10 MW. RD661/2007 and PO 3.7.
  - Control Centre's Control System has to be connected to the CECRE via ICCP channels and send measurements (P, Q, V, Wind Speed etc…).
  - Wind farms must receive and obey CECRE's limitations within 15 minutes.
  - Control Centres have to overcome test protocols with the CECRE.

Power control test with WGCC



Wind power curtailments due to fault ride-through on 27/03/2008

CC.AA.	REDUCCIÓN EMITIDA (MW)					
	9-10 h	10-11 h	11-12 h	12-13 h	13-14 h	14-15 h
Galicia	48	62	74	19	91	19
Asturias	6	35	23	11	14	5
P.Vasco	0	0	0	3	0	0
Navarra	8	0	0	0	0	0
La Rioja	0	5	2	1	0	0
C. León	94	207	224	81	228	67
C. Mancha	88	142	148	49	231	73
TOTAL	243	451	471	164	565	165

- Reduction orders in order to ensure system security in case of wind power losses after three phase fault, with possible loss of the French interconnection
- Reduction orders are hourly recalculated depending on wind power production.

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Approach to the Spanish Power System

Wind power integration

· Problematic issues for a TSO

· **REE solutions**

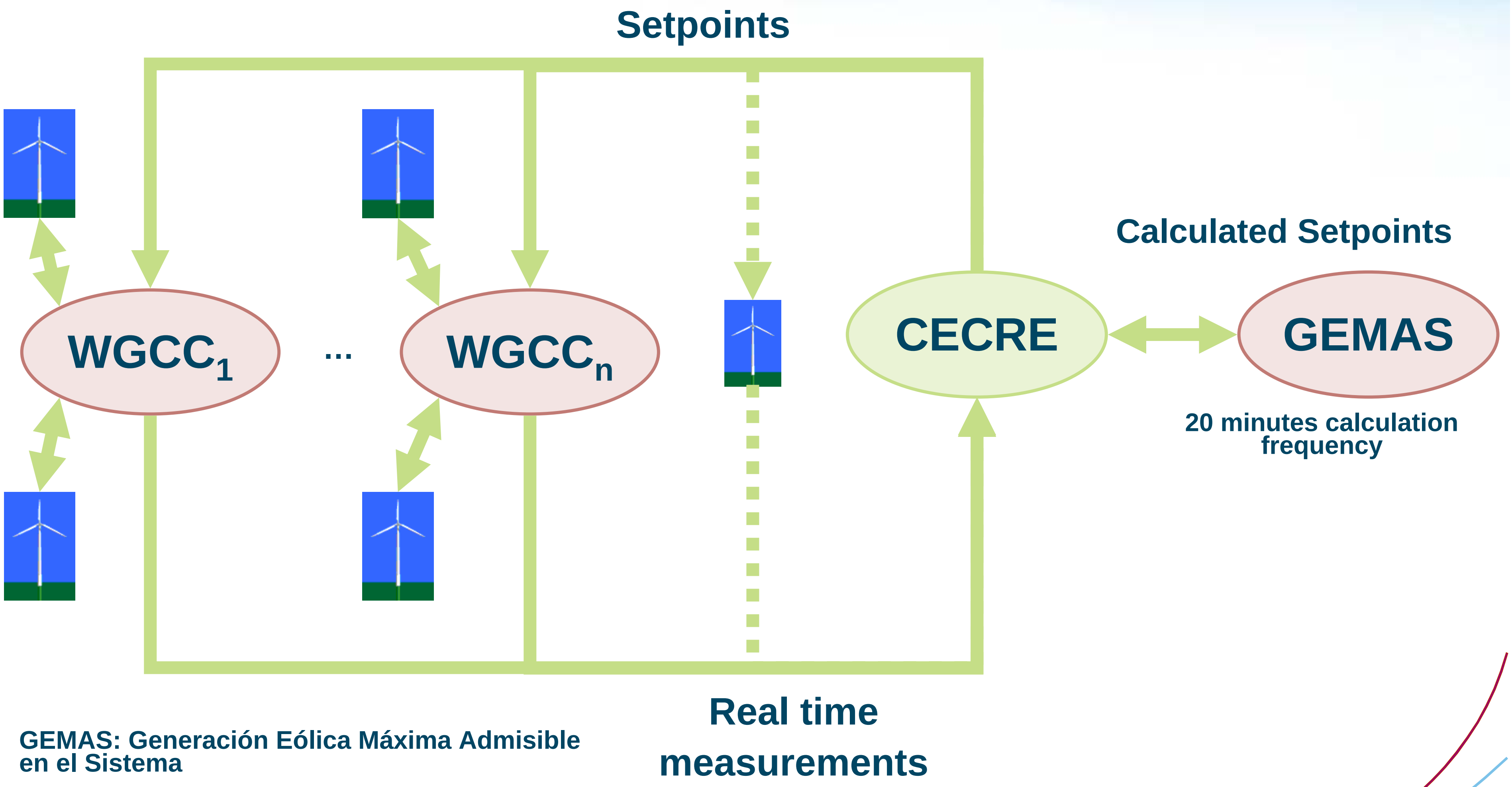
Maximum wind penetration studies

Control centre for renewable energies (CECRE)

Calculation of wind farm limitations (GEMAS)

Economic framework

Conclusions



GEMAS: Generación Eólica Máxima Admisible en el Sistema

WGCC: Wind Generation Control Centre

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Economic framework

- Since RD 661/2007 (May 2007), 2 options:
(yearly updates)
  - Regulated tariff: first 20 years,73 €/MWh. Afterwards, 61 €/MWh
  - Market: first 20 years, market hourly price + 29 €/MWh (Max. 85€/MWh – Min 71 €/MWh). Afterwards market hourly price.

  … until 85% of 20.155 MW goal is reached. New framework in 2010.

- Power factor bonus: -4% to +8% of 78 €/MWh depending on time of day

- If approved before 2008 (before fault-ride-through requirements of PO 12.3), until 2013 bonus of 3.8 €/MWh once they adapt to the new requirements, otherwise they additionally lose the 29€/MWh bonus.

- Repowering: up to 2.000 MW, receiving an additional bonus of up to 7€/MWh until 2017 if they fulfil requirements of PO 12.3 and RD 661 (connection to WGCC)

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CONCLUSIONS

- **Present**
  - **Wind energy in Spain has reached high penetration levels (10% of annual energy) and these levels will continue to rise for several years**
  - **Control and supervision of special regime generation needed (importance of certification procedures). The market cannot and does not always ensure security of the system without intervention of the System Operator.**
  - **In June 2006 Special Regime Control Centre (CECRE) was commissioned by Red Eléctrica de España in order to safely integrate present and expected generation**
  - **GEMAS (the application running behind the CECRE) complements complex off-line transient studies with faster and easier static studies making real time simulations possible. GEMAS would not be necessary if 100% of wind generators presented fault-ride-through capability…**
  - **If system is at risk, limitations are issued automatically maximizing generation while keeping the system safe**
  - **Integration of wind farms will be easier as they adapt to the new “grid code”, but other limitations might arise due to power balance feasibility or congestions in evacuation, which are solved from the CECRE**
  - **Wind energy saves fuel, but little capacity investment**

CONCLUSIONS

- **Near future**
  - **Active contribution to voltage control**
  - **Electronic problems will be solved and allow better electric behaviour than conventional generators**
  - **Need to substitute in Spain older generators to increase wind integration**
  - **The only problems of wind power will be those associated to wind volatility and demand coverage –> higher use of secondary and tertiary reserves, wind curtailments**

- **…further future**
  - **Improvement of wind power forecasts?**
  - **Contribution to primary reserve?**
  - **Higher participation of Demand Side Management?**
  - **Wind energy storage in additional pumping units and hydrogen cells?**

Thank you for your attention

RED ELÉCTRICA DE ESPAÑA

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